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DESIGN, FABRICATE AND TEST PROJECTILE,
40-MM, M433 HEDP WITH INCENDIARY
ENHANCEMENT

John H. Meier, et al

Chamberlain Manufacturing Corporation

Prepared for: . .

Army Materiel Command

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13. ABSTRACT Chamberlain Manufacturing Corporation was contracted on 2 April 1973 under Picatinny Arsenal Contract No. DAAA21-73-C-0476 to design, modify and test Projectile, 40-mm, HEDP, M433 with incendiary enhancement. The purpose of this program was to determine the degree to which terminal effectiveness of the round was enhanced by adding incendiary material to the apex of the shaped charge cone. All necessary inert- and live-loaded standard M433 test items were provided as Government-furnished material. Throughout this program, Chamberlain varied the parameters of Incendiary Length, Diameter, Geometry, Material and Munition Standoff. Evaluation was made of the functional parameters of Penetration, Thermal Output and Peak Pressure and Impulse. Within the program Scope of Work, the optimum incendiary round was deemed to be one assembled with a tubular sponge zirconium incendiary slug having a uniform I.D., one-half inch in diameter by five-eighths inch in length. In terms of cone diameter (CD) of the shaped charge liner at its largest dimension, the optimum incendiary slug measures 0.4 CD diameter by 0.5 CD length. A round assembled to these specifications will produce a significant increase (over the performance of the standard round) in pressure and temperature rise within an enclosed target, and the presence of burning incendiary particles will increase the round's potential for setting fires within the target. Some degradation in penetration performance was sustained with the modified			

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<p>hardware. Chamberlain believes that a substantial increase in penetration can be obtained by assembling the incendiary slug described above within rounds fabricated to provide an additional one-eighth inch of explosive head height.</p> <p>At the conclusion of the program, Chamberlain furnished the Government with 50 modified rounds, each assembled with the sponge zirconium slug having the dimensions and configuration deemed optimum within the limits of the program.</p> <p style="text-align: center;"><u>KEY WORDS</u></p> <p>Armor Penetration Conical Shaped Charge Weapons Detonation Wave-Shaping Incendiary Kill Mechanism M433 HEDP Pressure Rise Shaped Charge Shaped Charge Incendiary Follow-Through Spall Temperature Rise Terminal Effectiveness 40-mm Projectiles</p>						

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CARTRIDGE CASE ASSEMBLY
(3844609)

MODIFIED CUP & LINER
LOADING ASSEMBLY
(CMC DWG J8029-19)

FUZE ASSEMBLY
(8886360)

MYLAR TAPE

INCENDIARY
(CMC DWG J8029-18)

MODIFIED LINER
(CMC DWG J8029-6)

RETAINING RING
(8886340)

CARTRIDGE, 40 MM
HEDP, M433, MODIFIED
INCENDIARY FOLLOW THROUGH

AD _____

CHAMBERLAIN MANUFACTURING CORPORATION
RESEARCH AND DEVELOPMENT DIVISION

DOCUMENT No. C8029-PR-013

DESIGN, FABRICATE AND TEST
PROJECTILE, 40-MM, M433 HEDP
WITH INCENDIARY ENHANCEMENT

FINAL TECHNICAL REPORT
2 April 1973 - 29 May 1974

Prepared By
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James C. Hupp

SUBMITTED TO:
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Dover, New Jersey 07801

CONTRACT DAAA21-73-C-0476
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The findings in this report are not to be construed
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FINAL TECHNICAL REPORT
CONTRACT DAAA21-73-C-0476

ABSTRACT

Chamberlain Manufacturing Corporation was contracted on 2 April 1973 under Picatinny Arsenal Contract No. DAAA21-73-C-0476 to design, modify and test Projectile, 40-mm, HEDP, M433 with incendiary enhancement. The purpose of this program was to determine the degree to which terminal effectiveness of the round could be enhanced by adding incendiary material to the apex of the shaped charge cone. All necessary inert- and live-loaded standard M433 test items were provided as Government-furnished material.

Throughout this program, Chamberlain varied the parameters of Incendiary Length, Diameter, Geometry, Material and Munition Standoff. Evaluation was made of the functional parameters of Penetration, Thermal Output, and Peak Pressure and Impulse.

Within the program Scope of Work, the optimum incendiary round was deemed to be one assembled with a tubular sponge zirconium incendiary slug having a uniform I.D., one-half inch in diameter by five-eighths inch in length. In terms of cone diameter (CD) of the shaped charge liner at its largest dimension, the optimum incendiary slug measures 0.4 CD diameter by 0.5 CD length. A round assembled to these specifications will produce a significant increase (over the performance of the standard round) in pressure and temperature rise within an enclosed target, and the presence of burning incendiary particles will increase the round's potential for setting fires within the target. Some degradation in penetration performance was sustained with the modified hardware. However, test data indicate that a substantial increase in penetration can be obtained by assembling the incendiary slug described above within rounds fabricated to provide an additional one-eighth inch of explosive head height.

At the conclusion of the program, Chamberlain furnished the Government with 50 modified rounds, each assembled with the sponge zirconium slug having the dimensions, configuration, and material deemed optimum within the limits of the program.

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1. INTRODUCTION

1.1 Background

1.1.1 Defeat of armored targets, such as tanks and APC's, long has been a major problem of explosive ordnance. Shaped charge technology has advanced sufficiently that one may accurately predict the ability of a conical shaped charge to perforate a certain thickness of armor. However, perforation of protective armor is not necessarily analogous to target defeat. Defeat of a tank requires damage to components sufficient to preclude further successful operation of the vehicle. Defeat of an APC may be related either to vehicle defeat or to injury of personnel within the vehicle.

1.1.2 Damage mechanisms in addition to perforation which may contribute to target defeat include spallation, increase of pressure within the target, temperature increase within the target as well as local burning caused by jet particles. These all may be enhanced by addition of incendiary material to the warhead. Catastrophic (k) kills may be achieved by utilizing stored energy within the target, including ignition of fuel and/or stored ammunition. Ability to ignite these materials may be increased greatly by using incendiary material in the follow-through mode. For example, the probability of igniting Diesel fuel within a certain vehicle target may be substantially increased merely by changing the shaped charge liner material from copper to aluminum.¹ This enhancement may be even more pronounced if higher yield incendiaries such as zirconium or pyrophoric rare earths are used.

¹Research and Development of Material, Engineering Design Handbook, Elements of Terminal Ballistics, Part 2, Collection and Analysis of Data Concerning Targets (U), Headquarters, U. S. Army Materiel Command, Washington 25, D. C., AMC Pamphlet AMCP 706-161, AD 389 318L, November 1962 (SECRET).

1.1.3

Chamberlain Manufacturing Corporation in 1973 completed work on Contract F08635-72-C-0220 for Eglin Air Force Base in which a study was made of the effects of the addition of an incendiary follow-through slug at the apex of a conical shaped charge cone. Near the conclusion of this program, the Company submitted a proposal to Picatinny Arsenal for a parametric study of shaped charge enhancement by addition of incendiary follow-through material to the apex of the shaped charge cone in the 40-mm, M433 dual purpose round.

1.2

General Overview of the Program

1.2.1

Effective 2 April 1973, Chamberlain started work on Contract No. DAAA21-73-C-0476, a program originated to design, fabricate and test the 40-mm, M433 HEDP Round, modified with an incendiary slug at the apex of the shaped charge cone. The investigation which was conducted under the subject contract varied the following parameters in order to determine the optimum incendiary configuration for use in Projectile, 40-mm, M433 HEDP.

- Incendiary Length
- Incendiary Diameter
- Incendiary Geometry
- Incendiary Material
- Munition Standoff

1.2.2

During the course of the program, Company engineers investigated the degree to which the terminal effectiveness of the round was enhanced by addition of the incendiary material, by measuring the following functional parameters:

- Penetration
- Thermal Output
- Peak Pressure and Impulse

1.2.3

In accordance with the Amended Scope of Work for the subject contract, dated 26 March 1973, the Government furnished Chamberlain with all necessary live- and inert-loaded metal parts assemblies. The inert-loaded assemblies were utilized in Chamberlain's development of drilling techniques necessary for modification of the test hardware.

1.2.4

Early in the contract delays were encountered in receiving shipments of required munition components, causing the test portion of the program to be moved into the 1973-74 winter season. Because Iowa has a severely cold winter climate, conducting tests in ambient air temperature would have been undesirable, with the likelihood of deleterious effects upon the

resulting data evaluations. For the reasons stated in this paragraph, modifications to the contract became necessary in order to provide sufficient time for the tests to be conducted under favorable weather conditions. The net effect of these modifications was to change the contract completion date from 2 October 1973 to 29 May 1974, with no change in the estimated cost or the fixed fee.

1.2.5 The following criteria were used to evaluate optimum incendiary material and configuration (listed in descending order of importance):

- Minimum degradation to penetration
- Enhancement of post-armor effectiveness
- Residual penetration capability

1.2.6 After all tests were completed and all data reduced, the following parameters were considered optimum, within the scope of the subject program:

Incendiary Material:	Sponge Zirconium
Incendiary Configuration:	Tubular, having straight I.D.
Incendiary Length:	0.5 Cone Diameter (CD)
Incendiary Diameter:	0.4 Cone Diameter
Munition Standoff:	1.0 Cone Diameter (Hardware assembled with incendiary slug)

Further discussion of these optimizations is provided in Sections 4 and 5 of this report.

1.2.7 At the end of the contract, 19 control (standard, unmodified) rounds and 71 modified rounds had been test-fired. Data were compiled and evaluated as presented within this Final Technical Report, and the following modified hardware was shipped to Picatinny Arsenal:

50 Complete, Modified Rounds

1.2.8 This program demonstrated the feasibility of adding incendiary to enhance post-armor effectiveness, but with an attendant degradation in penetration. A follow-on effort can restore penetration capability while retaining the post-armor effectiveness obtained during this initial effort.

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2. HARDWARE

2.1 General Description

- 2.1.1 Test hardware consisted of both standard and modified 40-mm, M433 dual purpose rounds. Modification of the hardware consisted of truncating the shaped charge cone at the appropriate height and placing an incendiary follow-through slug at the apex of the truncated cone, as shown in Photo No. 10043 on the following page.

2.2 Identification Code

- 2.2.1 An identification code was assigned to each test item of each series. These code assignments are presented in Figure 1 on Page 7.

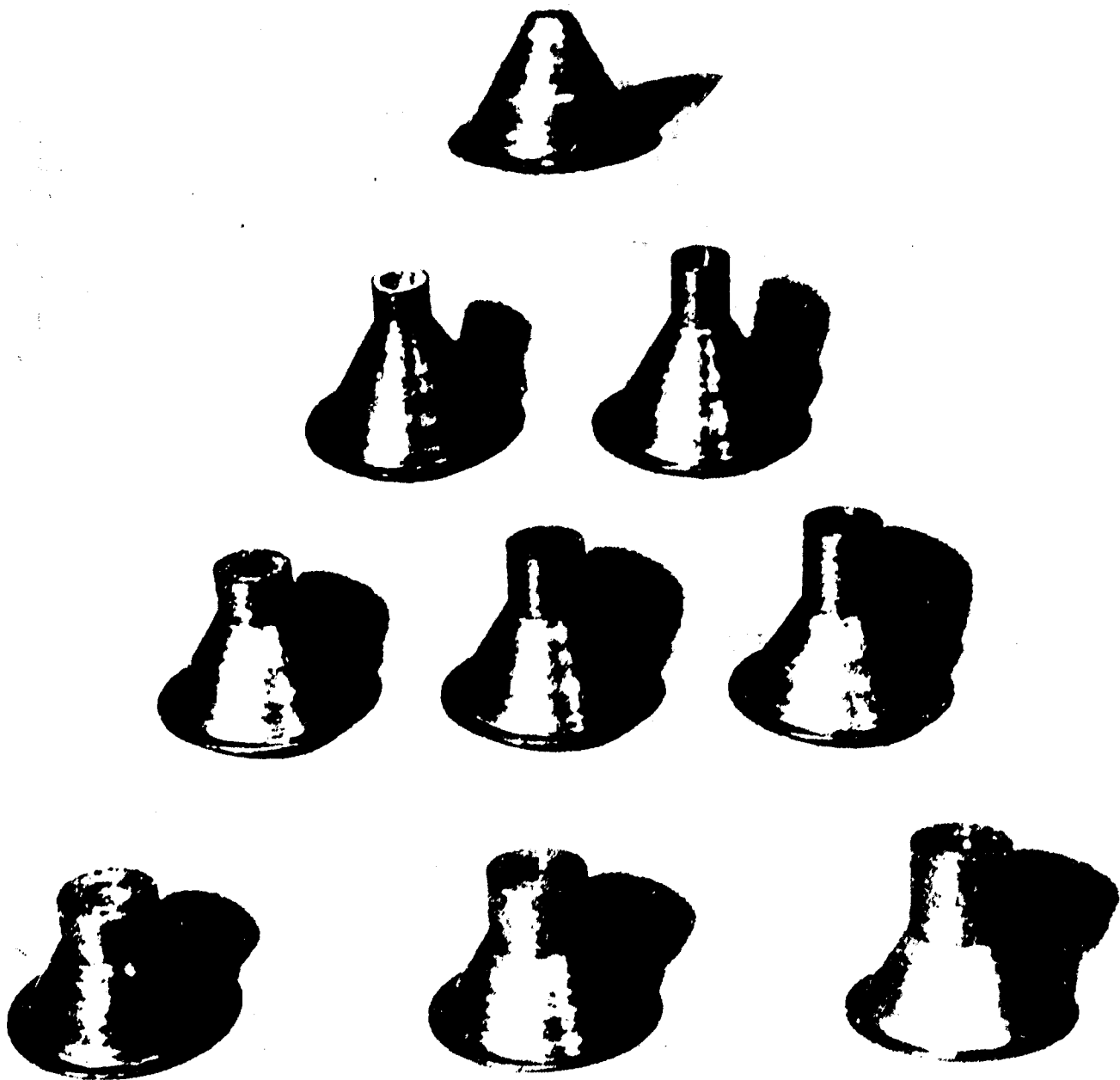
2.3 Modification by Explosive Drilling

2.3.1 Equipment Used:

1. Drill press remotely operated with exhaust system
2. Collet holding fixtures
3. Locating fixtures (per Drawing No. J8029-4A, in the Appendix)
4. Standard end mill

2.3.2 Procedure for Drilling:

1. Place collet holding fixture on the drill press and align the fixture directly under the spindle.
2. Insert locating fixture (Drawing No. J8029-4A) into chuck of drill press.
3. Place loading assembly minus liner and retaining ring into collet holding fixture. Bring down drill press handle and the locating fixture will center item vertically. Lock down collet. Remove locating fixture from chuck.
4. Place end mill into drill press chuck. Drill to desired depth. Remove item from collet.



PHOTOGRAPH NO. 10043

TYPICAL TEST HARDWARE

Incendiary Enhancement of Projectile, 40-MM, HEDP, M433

TOP TO BOTTOM:

- ROW 1 - Liner without Incendiary; Test Series 1
- ROW 2 - Liners having 0.3 Cone Diameter Incendiary; Test Series 2
- ROW 3 - Liners having 0.4 Cone Diameter Incendiary; Test Series 2
- ROW 4 - Liners having 0.5 Cone Diameter Incendiary; Test Series 2

Figure 1

TEST HARDWARE IDENTIFICATION CODE

TEST SERIES 1	<div> <div>1 X</div> <div>X</div> <div>X</div> </div> <div> <div>Standoff (CD)</div> <div>Test Type</div> <div>Serial No.</div> </div> <div> <div>1</div> <div>2</div> <div>3</div> <div>5</div> </div> <div> <div>P - Penetration</div> <div>B = Press.-Temp.</div> <div>D = Photo Doc.</div> </div>
TEST SERIES 2	<div> <div>2 X</div> <div>X</div> <div>-</div> <div>X</div> <div>X</div> </div> <div> <div>Incendiary Length</div> <div>Incendiary Diameter</div> <div>Same As Series 1</div> </div> <div> <div>3 = .3 Cone Dia.</div> <div>4 = .4 Cone Dia.</div> <div>5 = .5 Cone Dia.</div> </div> <div> <div>3 = .3 Cone Dia.</div> <div>4 = .4 Cone Dia.</div> <div>5 = .5 Cone Dia.</div> </div>
TEST SERIES 3	<div> <div>3 X</div> <div>-</div> <div>X</div> <div>X</div> </div> <div> <div>Incendiary Material</div> <div>Same As Series 1</div> </div> <div> <div>Z = Zirconium</div> <div>M = Misch Metal</div> </div>
TEST SERIES 4	<div> <div>4 X</div> <div>-</div> <div>X</div> <div>X</div> </div> <div> <div>Incendiary Material</div> <div>Same As Series 1</div> </div> <div> <div>Z = Zirconium</div> <div>M = Misch</div> </div>
TEST SERIES 5	<div> <div>5 X</div> <div>-</div> <div>X</div> <div>X</div> </div> <div> <div>Standoff (CD)</div> <div>Same As Series 1</div> </div> <div> <div>2</div> <div>3</div> </div>

2.3.3 Procedure for assembling test item (see Figure 2 on the following page):

1. Place the liner and incendiary assembly into the drilled explosive assembly. Press retaining ring Part No. 8886340 into place, using die block and punch (Drawing Nos. J8029-3A, and -2A, respectively, in the Appendix).
2. Place spitback assembly Part No. 8886351, using Loctite 404², into fuze body Part No. 8886356.
3. Place fuze body with spitback into the loaded assembly using Loctite 404² and modeling clay.
4. Place XM-70 Detonator directly over spitback using Loctite 404² and modeling clay.

² A product of Loctite Corporation, Newington, Connecticut.

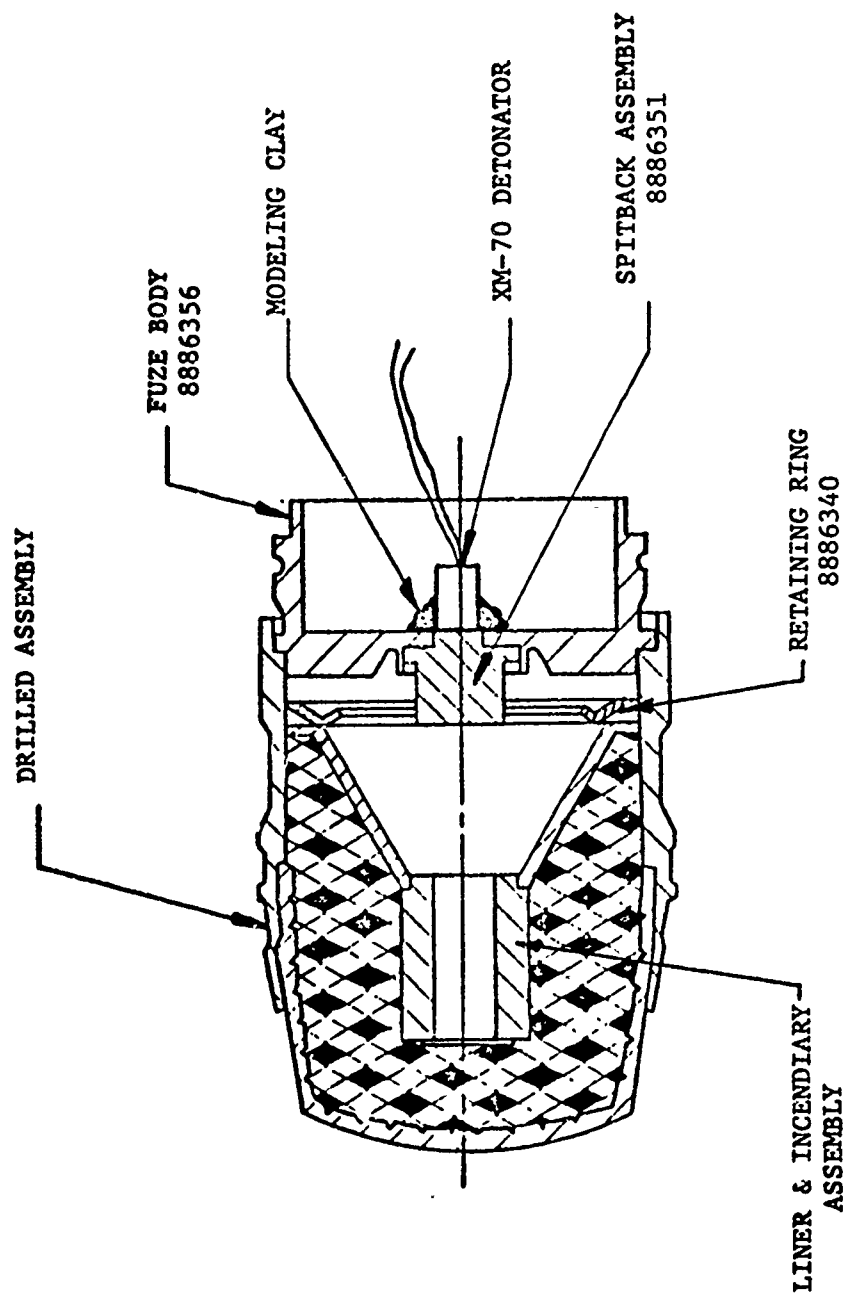


Figure 2
ASSEMBLY OF TYPICAL TEST ITEM

3. TEST SETUPS

3.1 Penetration Tests

- 3.1.1 The test items (see Figure 2 on Page 9) were placed at pre-determined standoff from the top target plate, using an expendable standoff block and covered by a steel forging to shield the area from the detonation and fragmentation. Target material included stacked, cold rolled C-1018 Steel plates, two inches thick by six inches square and one inch thick by six inches square (see Figure 3 on the following page).

3.2 Pressure-Temperature Tests

- 3.2.1 A pressure-temperature chamber³ was used to measure pressure and temperature rise within an enclosed volume (see Figures 4 and 5). This fixture was instrumented with two Kistler 6034B⁴ acceleration-compensated pressure transducers having a dynamic range of 0 to 5000 psi, and two Hy-Cal Zig-Zag Thermocouples⁵, Model TC-2345-C-K-5, temperature range -50°F to 350°F, 5 mil. chromel/alumel wire encased in kapton, with a response time of 20 ms. The outputs of these devices were recorded on a seven-channel data tape recorder and then were transferred to Polaroid film by use of an oscillograph. As a back-up to the pressure transducers, two each 2024-T3 aluminum butterfly gages having 0.063- and 0.080-inch thicknesses were used. The butterfly gage, strictly a mechanical device, is a double cantilever beam which, when permanently deformed, is a self-recorded source of information. It is constructed of a thin strip of aluminum, supported in the center, which fits snugly in an opening of the same size in the test chamber. New gauges are used with each test; these are permanently deformed by the pressure of the expanding gases inside the chamber at the moment of testing. The amount of deformation varies directly with the amount of pressure to which the gauge is subjected. The bending angle therefore can be interpreted directly in terms of the integrated impulse experienced over the unsupported surface of the beam. The term "butterfly" is used to describe the characteristic shape of the gauge after deformation.

³Garfinkel, D.R. and Brown, R.E., "Incendiary Agents Shaped Charge Follow-Through Warhead for Defeat of Hard Targets" (U), Phase III Report, SH1-6150-11, Shock Hydrodynamics, Inc., Contract DAAA15-68-C-0161, October 1969, AD 508244 (Secret)

⁴A product of Kistler Instrument Corporation, Clarence, New York

⁵A product of Hy-Cal Engineering Company, Santa Fe Springs, California

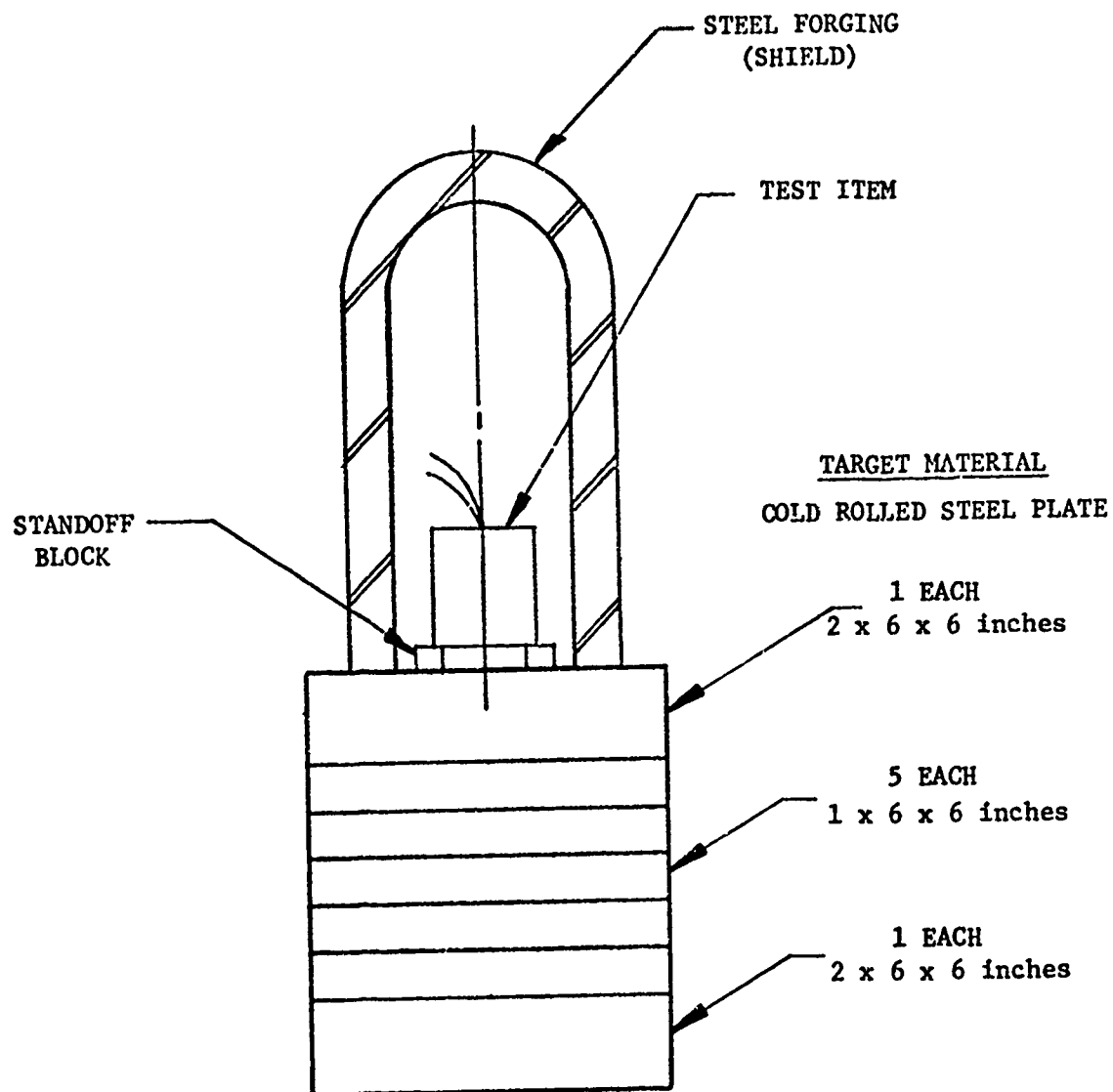


Figure 3
PENETRATION TEST
SET-UP

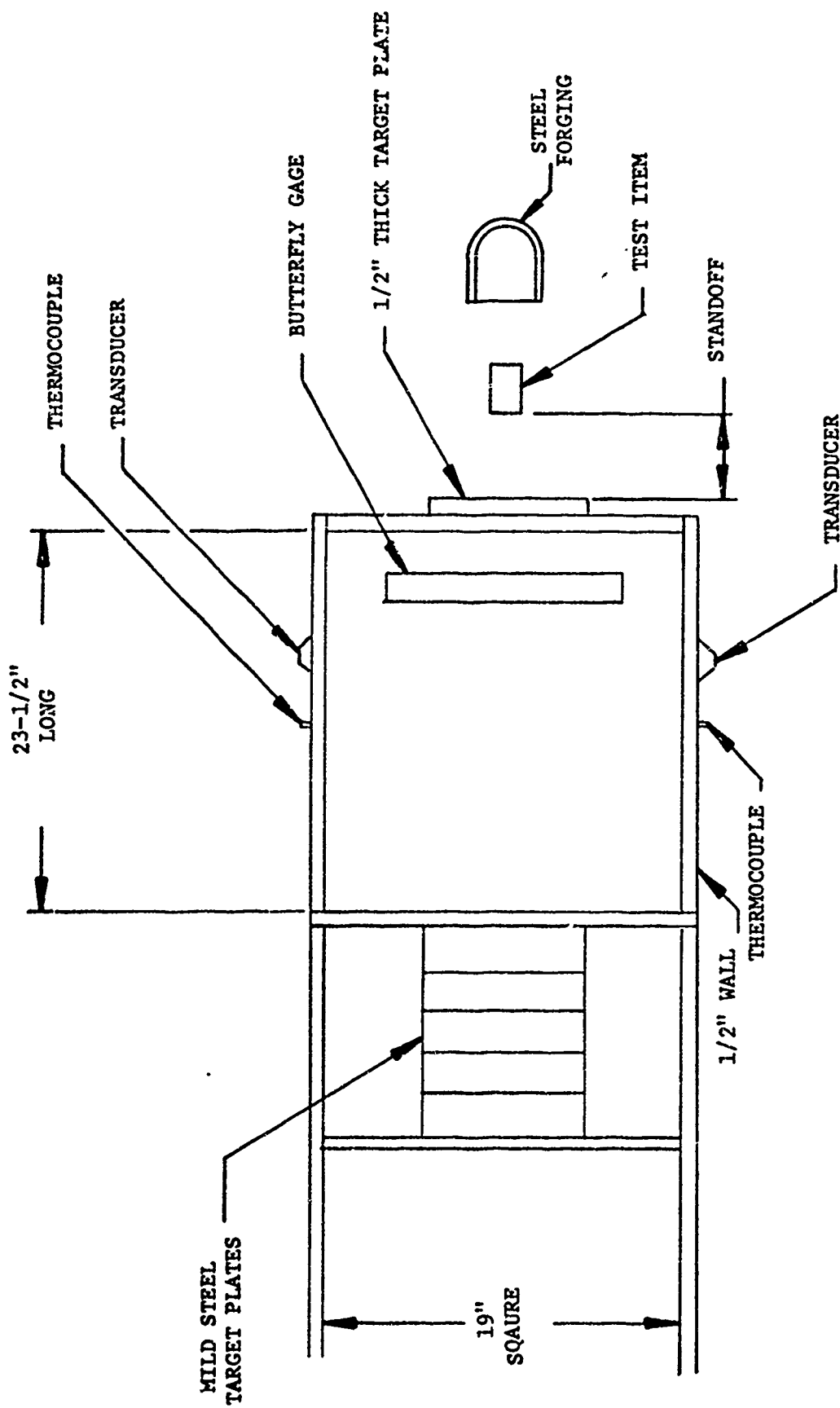


Figure 4
TEST CHAMBER

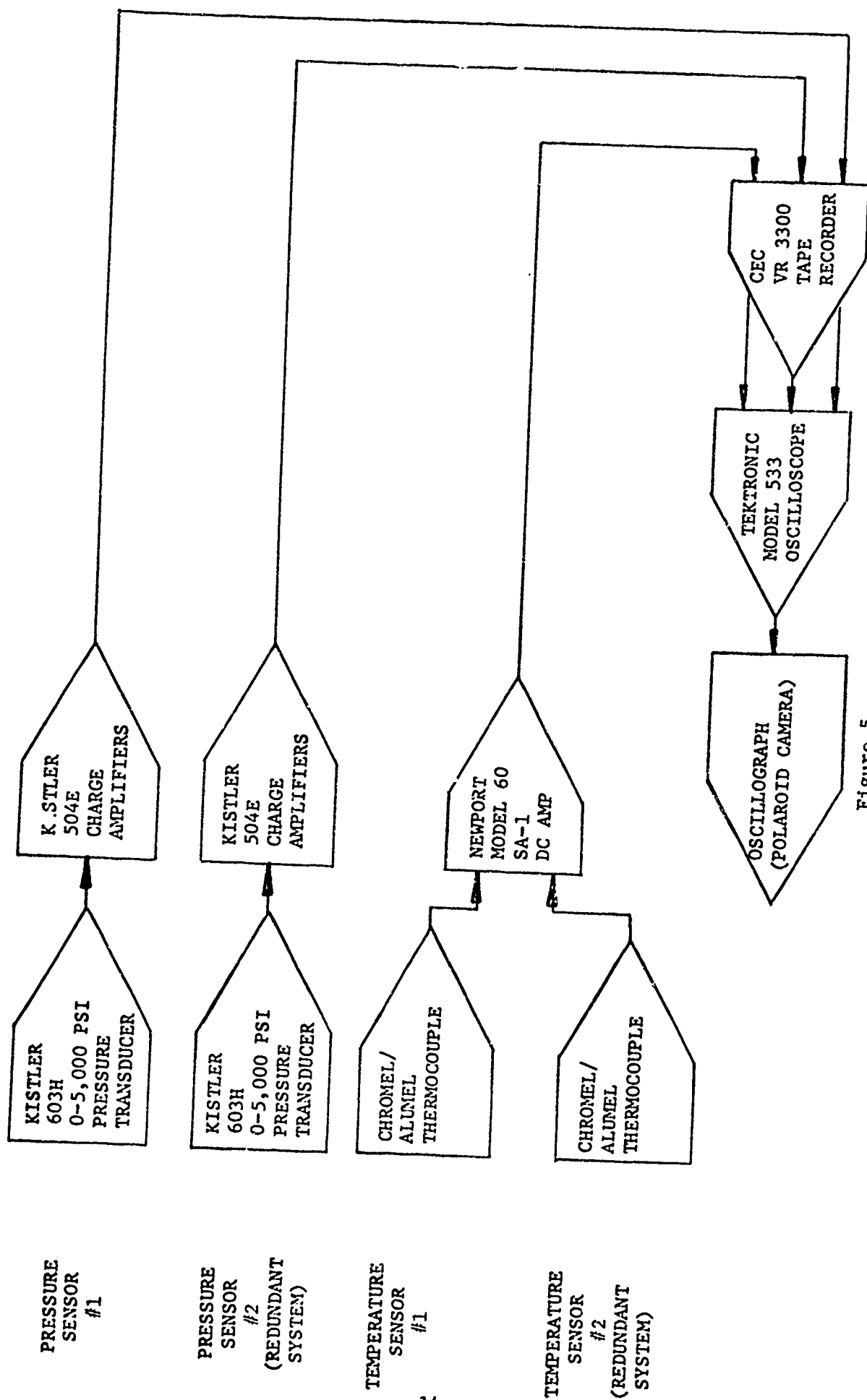


Figure 5

INSTRUMENTATION SCHEMATIC FOR TEST CHAMBER FIRING

3.2.2 A steel target plate one-half inch thick by five inches square was placed on top of the pressure-temperature chamber, with the test item (covered by a steel forging to shield the instruments from the detonation and fragmentation) placed at a predetermined standoff distance above the plate. After passing through the one-half-inch thick top plate and 25 inches of air, the shaped charge jet impinges on a stack of mild steel target plates, each one-inch thick by six-inches square, which were used to measure residual penetration capability.

3.3 Photo-Documentation Tests

3.3.1 The Photo-Documentation Tests were conducted to provide a visual record of the incendiary follow-through process. The test setup (see Figure 6 on the following page) consists of a steel target plate one-half inch thick by five inches square being placed within a barrel. The test item (Figure 2) is placed above the target plate at a predetermined standoff distance and covered by a steel forging to shield the cameras from the detonation and fragmentation. Two Fastax high speed framing cameras (approximately 5,000 frames per second) are used; these are positioned as shown in Figure 7 on Page 17.

3.2 The entire assembly is placed over an open area in order to facilitate camera coverage. Calibration marks (in feet) are provided on the wooden background to aid in the measurement of jet and follow-through velocities. A steel plate 1/8-inch thick is placed on the ground below the test item to provide a hard impact surface similar to that which might be encountered in an actual target.

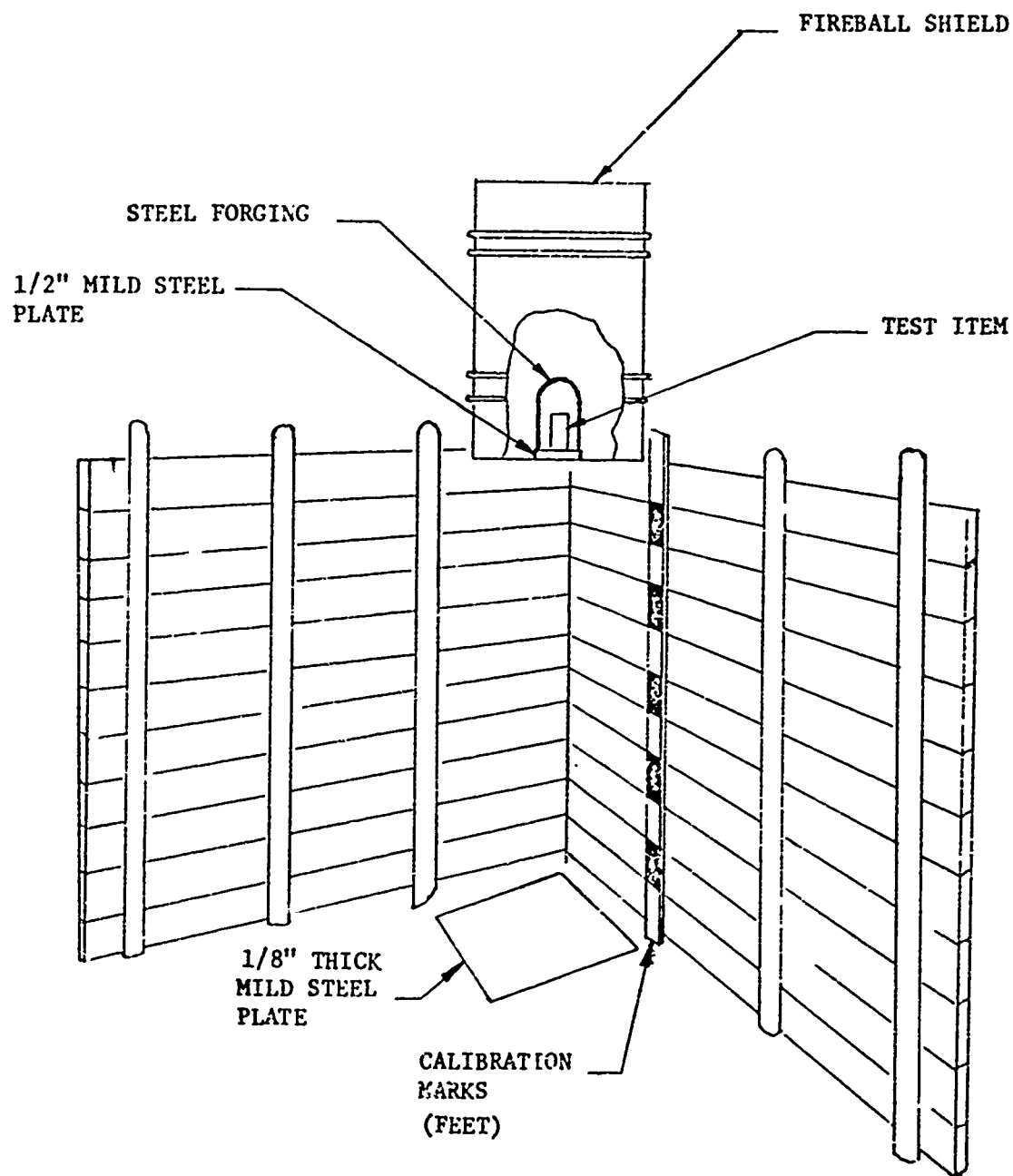


Figure 6
PHOTO-DOCUMENTATION SET-UP

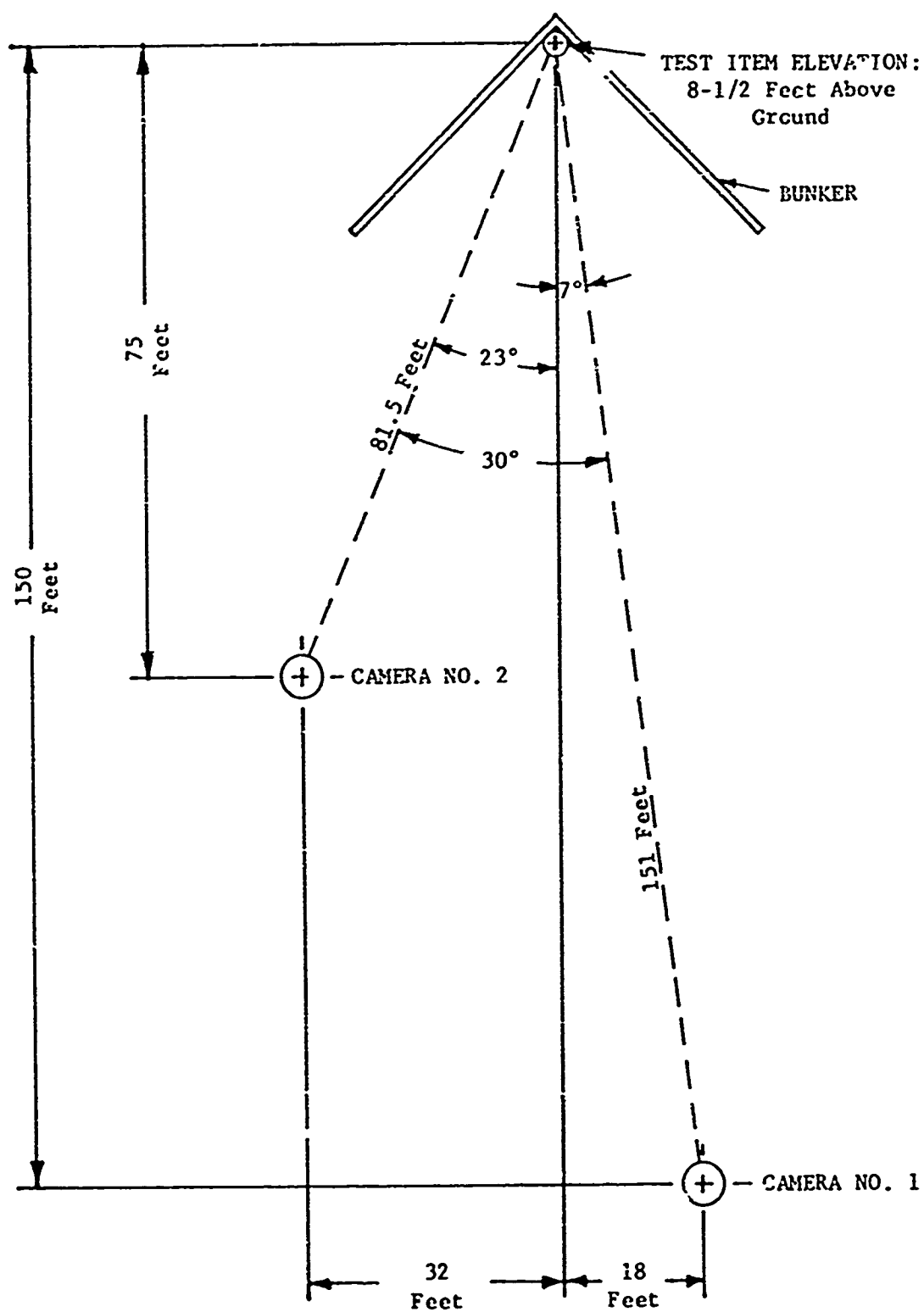


Figure 7

CAMERA LAYOUT FOR PHOTO-DOCUMENTATION TESTS

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4. TESTING

4.1 Objectives

4.1.1 The main objectives of the test program were:

1. To determine the optimum configuration for an incendiary follow-through slug to be added to the apex of the shaped charge cone of the M433, dual purpose 40-mm round.
2. To determine what improvements in performance are provided by the addition of this incendiary material.

Ninety (90) test firings were performed to investigate the effects on warhead performance resulting from varying the following parameters:

- Incendiary Length
- Incendiary Diameter
- Incendiary Material
- Incendiary Geometry
- Standoff Distance

4.1.2 The tests yielded data pertaining to amount of penetration into mild steel, and pressure and temperature rise occurring in a closed chamber behind a 1/2-inch thick steel target. All tests performed and results achieved are summarized in Table 1 on the following page.

4.2 Test Plan

The 90 tests were subdivided into five Test Series, in which parametric evaluations were made as follows:

<u>PARAMETER NO.</u>	<u>PARAMETER</u>	<u>NO. OF VARIATIONS TESTED</u>	<u>DIMENSIONS OR VARIABLES EVALUATED*</u>
1.	Incendiary Length	3	0.3, 0.4, 0.5**
2.	Incendiary Diameter	3	0.3, 0.4, 0.5
3.	Incendiary Material	2	Misch Metal; Zirconium
4.	Incendiary Geometry	2	Cylindrical I.D.; Tapered I.D.
5.	Standoff Distance	4	1, 2, 3, 5

TABLE I

SUMMARY OF TESTS

TEST SERIES	STANDOFF (CD)	INCENDIARY LENGTH (CD)	INCENDIARY DIAMETER (CD)	INCENDIARY MATERIAL	INCENDIARY INTERNAL CONFIGURATION	NUMBER OF TESTS				COMMENTS
						PENET.	PRES.- TEMP.	PHOTO DOC.	TOTAL	
1	1	---	---	None	---	3	6	1	10	Determine Baseline Performance for Unmodified Hardware.
	2					3	0	0	3	
	3					3	0	0	3	
	5					3	0	0	3	
									19	
2	1	0.3	0.3	Zirconium	Cylindrical	3	2	0	5	0.4 CD Incendiary Slug Diameter and 0.5 CD Incendiary Slug Length Established as Best Configuration
		0.4	0.3			3	2	0	5	
		0.3	0.4			3	2	0	5	
		0.4	0.4			3	2	0	5	
		0.5	0.4			3	2	0	5	
		0.3	0.5			3	2	0	5	
		0.4	0.5			3	2	0	5	
		0.5	0.5			3	2	0	5	
						3	2	0	5	
									40	
3	1	0.5	0.4	Zirconium Misch Metal	Cylindrical	0	2	1	3	Zirconium Established as Optimum Incen- diary Material.
						3	4	1	8	
									11	
4	1	0.5	0.4	Zirconium Misch Metal	Tapered	3	3	0	6	Cylindrical Established as Best Incendiary Internal Configuration.
						5	2	1	8	
									14	
5	2	0.5	0.4	Zirconium	Cylindrical	3	0	0	3	Generate Data For Penetration Versus Standoff Curve
	3	0.5	0.4			3	0	0	3	
									6	
						53	33	4	90	TOTALS

* Dimensions of Parameter Nos. 1, 2 and 5 above, are expressed in Cone Diameters (largest diameter of the shaped charge cone; i.e., 1.221 inches).

**Incendiary lengths that were evaluated were determined by projectile length limitations. In the case of the 0.3 CD diameter slug, the 0.5 CD length was not tested because this length would not leave sufficient head height for reliable high explosive initiation.

4.2.1.1 In testing for optimum incendiary material, misch metal was selected as one of the two candidates because it had been the optimum material of those tested under Eglin Air Force Base Contract No. F08635-72-C-0220, recently completed by Chamberlain, which was a feasibility study of the Shaped Charge/Incendiary Follow-Through Concept ⁵. The misch metal used was a 4% aluminum alloy composition having good mechanical and anti-corrosion properties.

A hafnium alloy, compressed sponge zirconium composition having particles approximately 0.080 inch in diameter, was selected as the second incendiary material to be tested. The material specification for the incendiary material provided by the vendor is in the Appendix. This material was selected for the following characteristics:

- High mechanical properties
- Easily Ignited
- Favorable Burn Duration

4.2.1.2 Two contours of the interior surface of the incendiary slug were tested. The contour used principally was a cylindrical void of 0.270-inch diameter, which is the spitback diameter incorporated in the liner of the standard 40-mm, M433 Round. The other contour evaluated was conical in configuration with the interior wall of the slug tapered from a minor diameter of 0.100 inch (with a 20° included angle) and widening to a major diameter of 0.270 inch. Company engineers believed that this taper might have produced some shaped charge jetting involving incendiary material and thereby might have changed the distribution of the incendiary material with respect to the conical shaped charge jet and slug.

⁵Concept Feasibility Studies of the Versatile Shaped Charge Follow-Through Technique (U), Chamberlain Manufacturing Corporation, Waterloo, Iowa 50705; Chamberlain Document No. C7953-PR-006, AFATL-TR-7355, AD 526 474L; March 1973 (CONFIDENTIAL)

4.3 Test Results

4.3.1 Test Series No. 1 -- Determination of Standard M433 Performance Characteristics

4.3.1.1 The first series of tests consisted of 19 firings. These were conducted to determine baseline performance characteristics for unmodified (standard M433) hardware. Evaluation of the unmodified hardware was achieved through three different types of tests. Twelve items (three each having four different standoffs) were fired into stacked mild steel in order to determine penetration capability. Additionally, six standard items were fired into the pressure-temperature chamber (see Figure 4 on Page 13) to determine pressure and temperature rise within a closed container, as well as residual shaped charge penetration capability. One photo-documentation test was conducted to provide visual evidence of the shape charged jet as well as to permit measurement of the relative duration of the fireball for the various designs (after completion of all other photo-documentation tests). Results of the Series 1 penetration and pressure-temperature tests are presented in Table II on the following page. Problems with instrumentation made it necessary to fire more tests than specified in the original test plan in order to obtain acceptable test data. (The instrumentation problems encountered are described in Subsection 4.4 of this report.) Because significantly large degradation of penetration occurred with the 5.0 CD standoff, it was decided additionally to test three rounds using a standoff distance of 3.0 CD in order to develop a more comprehensive standoff versus penetration relationship.

4.3.2 Test Series No. 2 -- Determination of Optimum Incendiary Dimensions

4.3.2.1 The purpose of the Second Test Series (40 tests) was to determine the optimum length and diameter of the zirconium incendiary follow-through slug. Five each of the eight combinations of incendiary length and diameter were fired; three each in penetration tests and two each in pressure-temperature tests. These test results were used as a basis for comparison between the various combinations of incendiary length and diameter. This series of tests resulted in the selection of the 0.4 CD incendiary slug diameter and 0.5 CD incendiary slug length as the best configuration. Results of these tests are presented in Table III on Page 24 and in Figures 8 through 12 on Pages 25 through 29.

(Text Continued on Page 30)

TABLE II
RAW TEST DATA
SERIES 1
BASELINE PERFORMANCE FOR
UNMODIFIED HARDWARE

TEST SERIAL NO.	PENET. DEPTH (in.)	TEST SERIAL NO.	PEAK PRESSURE (PSI)	THERMAL * OUTPUT (MV)	RESIDUAL PENET. (in.)	BUTTERFLY GAGE DEFLECTION	
						.063 THK. (in.)	.080 THK. (in.)
11-P1	3.80	11-B1	20	1.55	.90	N.D.	N.D.
11-P2	3.70	11-B2	20	.72	.80	N.D.	N.D.
11-P3	3.10	11-B3	N.D.	1.35	1.00	N.D.	N.D.
12-P1	2.40	11-B4	N.D.	N.D.	.75	1.39	.58
12-P2	4.25	11-B5	N.D.	N.D.	.94	1.15	.75
12-P3	4.35	11-B6	28	.45	1.00	1.28	.61
13-P1	3.80						
13-P2	4.40						
13-P3	4.10						
15-P1	1.00						
15-P2	1.90						
15-P3	0.80						

N.D. Designates no data recorded.

* SEE Figure 14, Page 49: "Temperature Rise Above Ambient Versus Thermocouple Output"

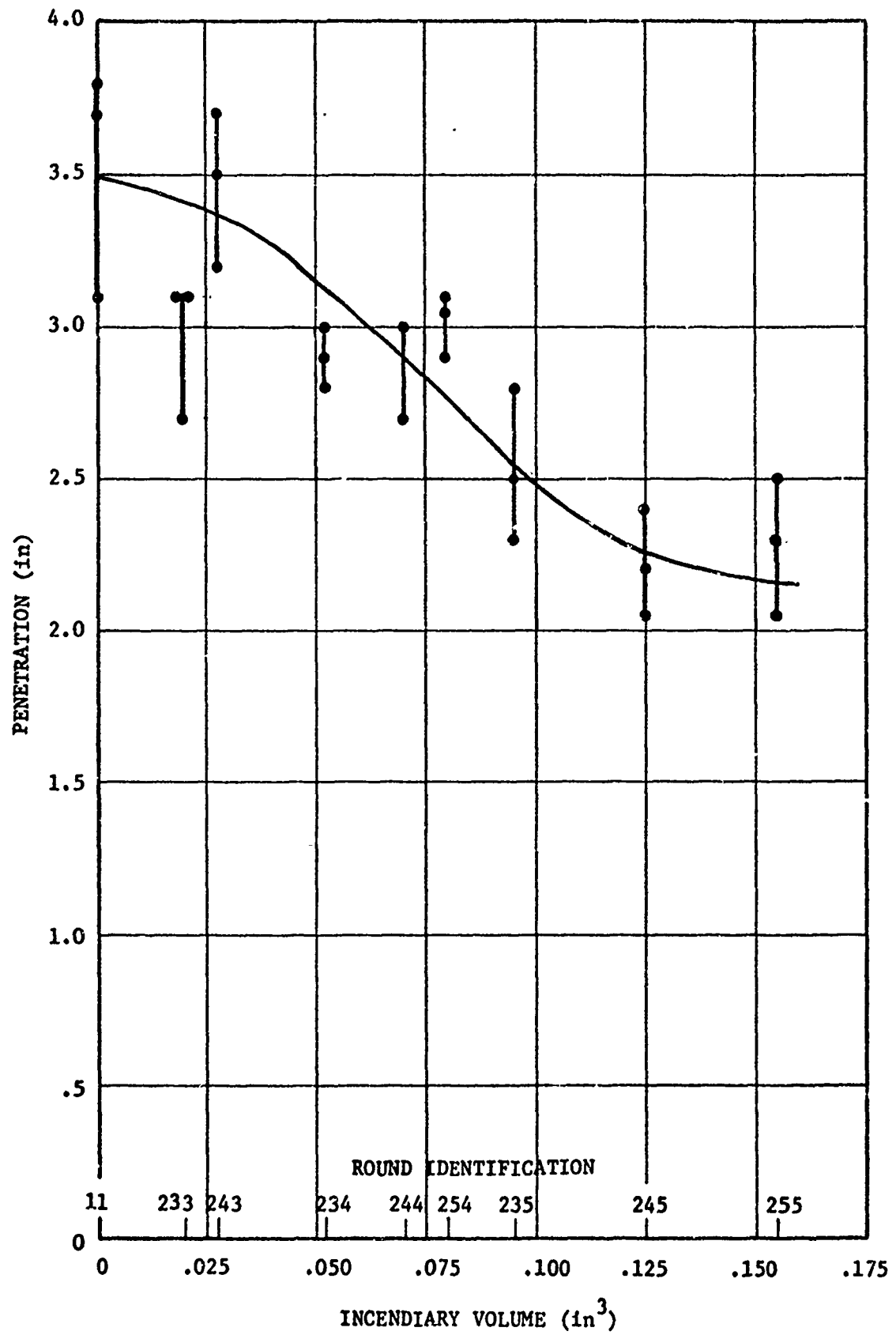
TABLE III
RAW TEST DATA
SERIES 2
DETERMINE OPTIMUM INCENDIARY
SLUG DIAMETER AND LENGTH

TEST SERIAL NO.	PENET. DEPTH (in.)	TEST SERIAL NO.	PEAK PRESSURE (PSI)	THERMAL * OUTPUT (MV)	RESIDUAL PENET. (in.)	BUTTERFLY GAGE DEFLECTION	
						.063 THK. (in.)	.080 Thk (in.)
233-P1	2.70	233-B1	30	1.10	1.10	1.58	.66
233-P2	3.10	233-B2	32	1.50	1.30	1.88	.80
233-P3	3.10	243-B1	26	1.30	1.10	1.58	.78
243-P1	3.70	243-B2	24	1.18	1.15	1.52	.67
243-P2	3.20	234-B1	42	0.85	.95	1.55	.75
243-P3	3.50	234-B2	36	1.42	.95	1.85	1.04
234-P1	2.80	244-B1	50	1.15	.95	1.71	.66
234-P2	2.90	244-B2	40	1.50	1.15	1.58	.62
234-P3	3.00	254-B1	50	1.65	1.30	2.12	1.12
244-P1	Low Order	254-B2	45	1.72	1.60	1.88	.88
244-P2	3.00	235-B1	50	1.54	.75	1.98	1.01
244-P3	2.70	235-B2	45	1.88	.65	2.12	1.14
254-P1	3.10	245-B1	50	2.45	.80	2.28	1.24
254-P2	2.90	245-B2	55	1.52	1.00	2.06	1.02
254-P3	3.05	255-B1	45	1.55	1.15	2.23	1.20
235-P1	2.50	255-B2	40	2.38	1.05	1.78	.88
235-P2	2.80						
235-P3	2.30						
245-P1	2.40						
245-P2	2.05						
245-P3	2.20						
255-P1	2.30						
255-P2	2.50						
255-P3	2.05						

*SEE Figure 14, Page 49: "Temperature Rise Above Ambient Versus Thermocouple Output".

Figure 8

PENETRATION VERSUS INCENDIARY VOLUME



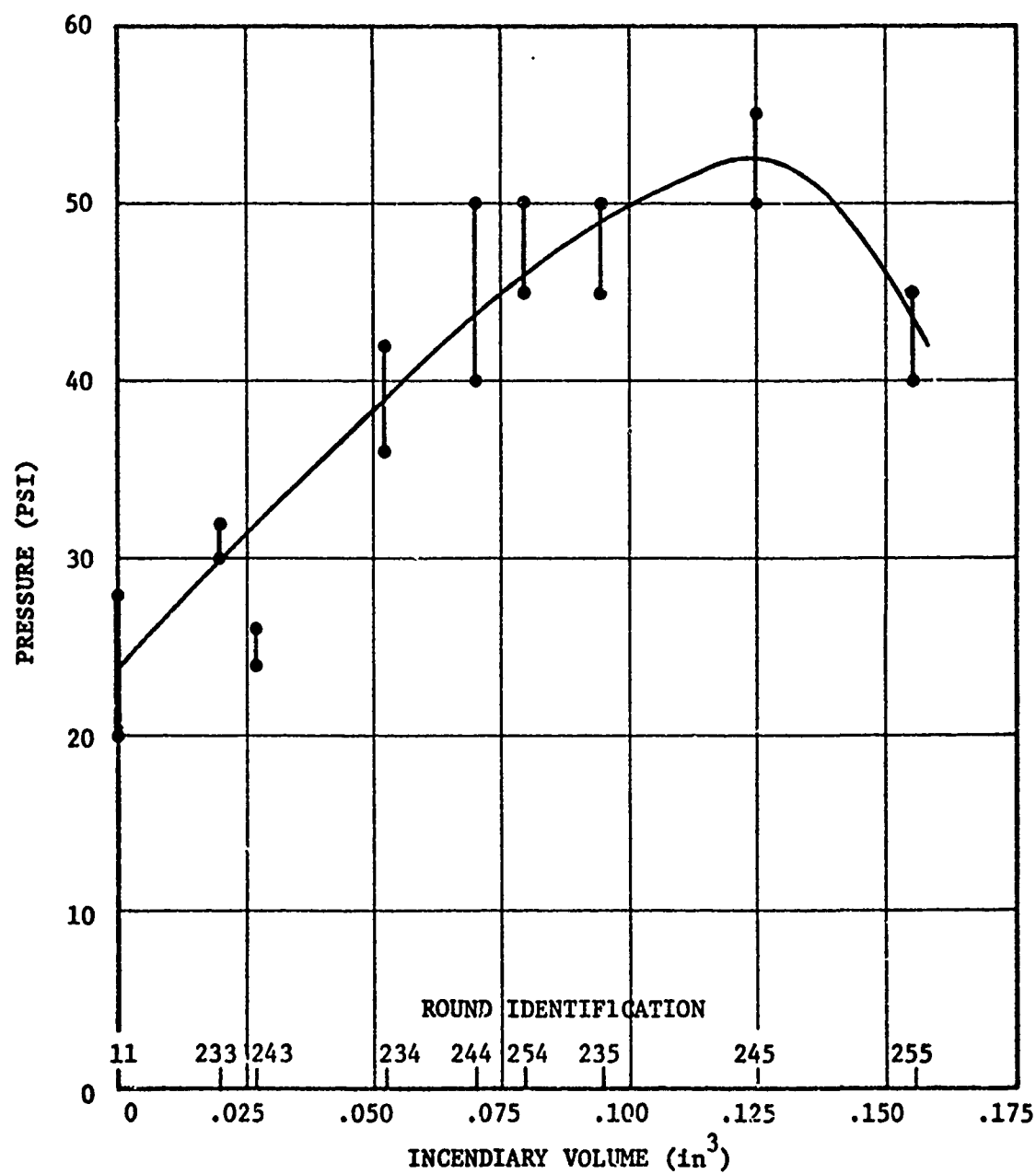
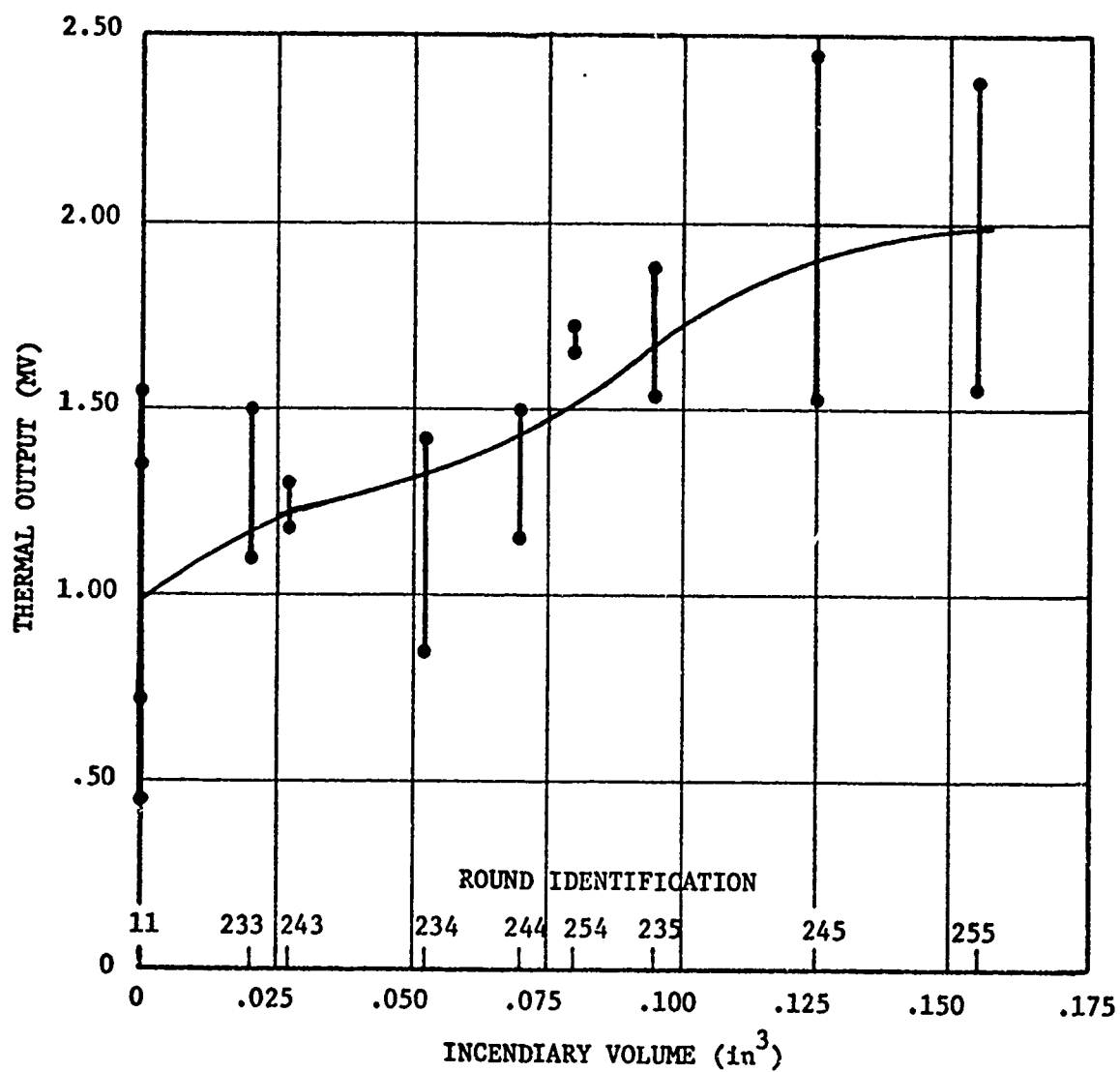


Figure 9
PEAK PRESSURE VERSUS INCENDIARY VOLUME

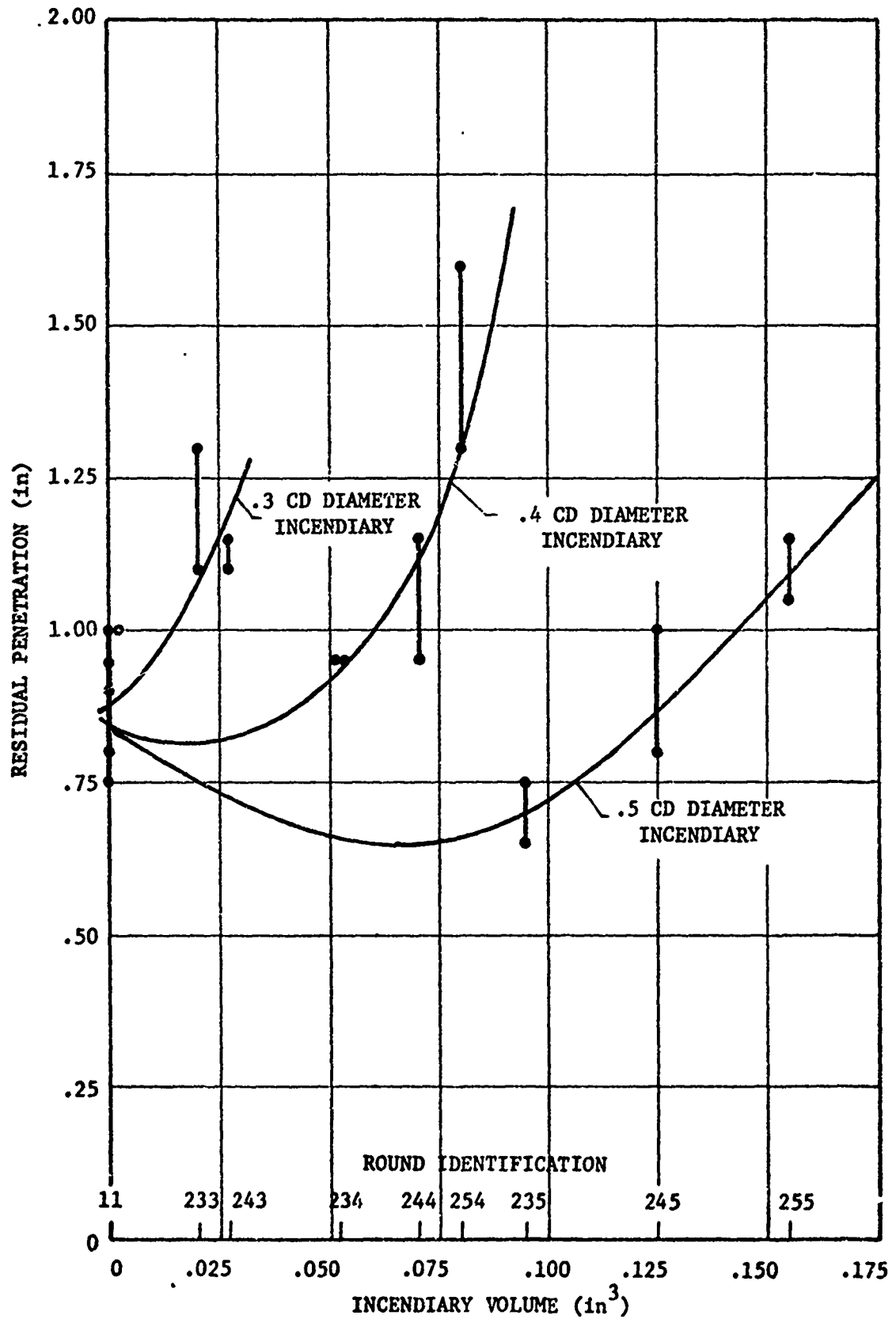


REF: Fig. 14, Page 49; "Temperature Rise Above Ambient Versus Thermocouple Output".

Figure 10
THERMAL OUTPUT VERSUS INCENDIARY VOLUME

Figure 11

RESIDUAL PENETRATION VERSUS INCENDIARY VOLUME



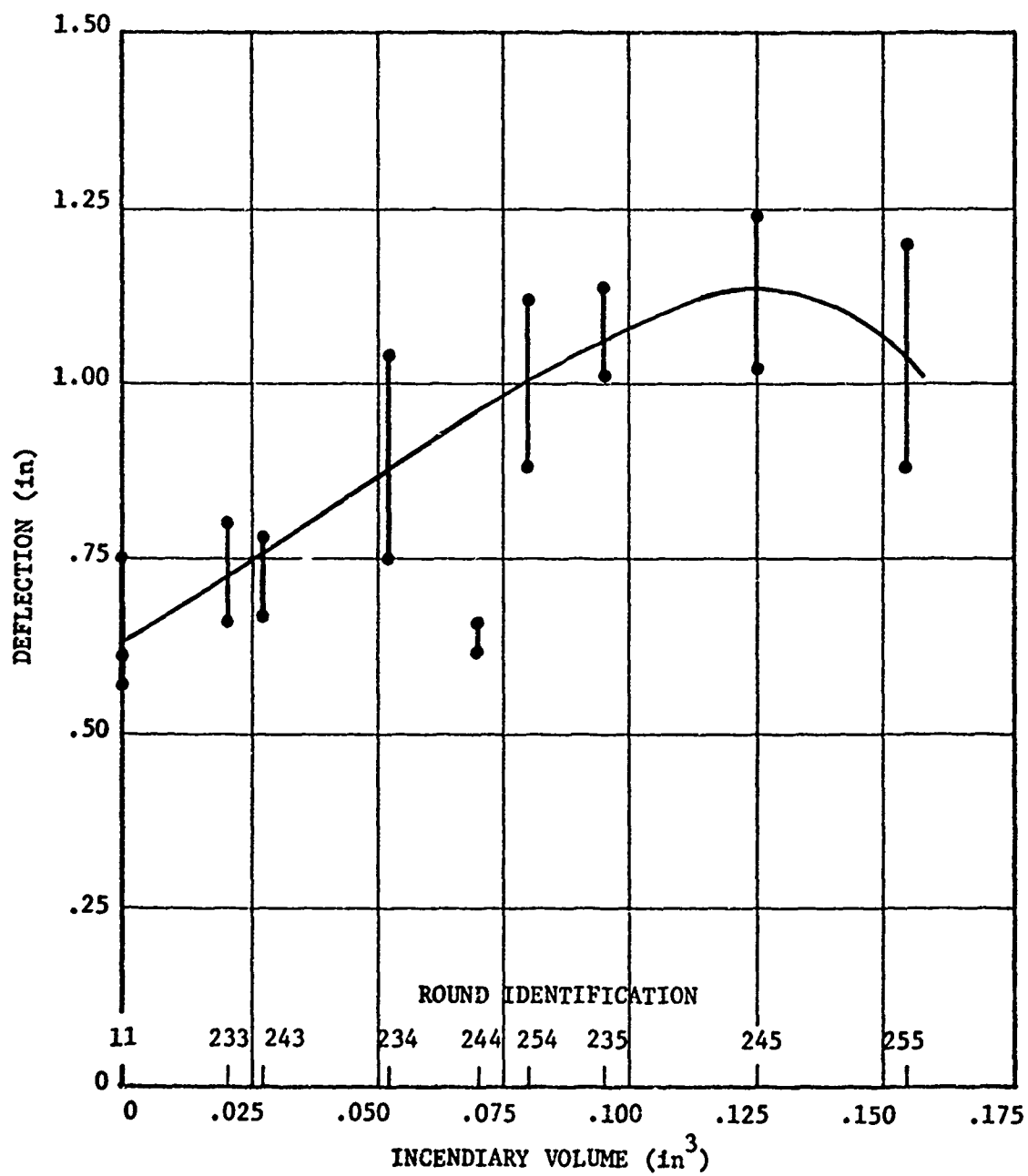


Figure 12
 BUTTERFLY GAGE DEFLECTION VERSUS INCENDIARY VOLUME
 (.080 THICK GAGE)

- 4.3.2.2 One low-order detonation was experienced in a penetration test which incorporated an incendiary slug having a configuration of 0.4 CD diameter and 0.4 CD length. The XM70 Detonator and spitback were initiated but the RDX sustained only low-order detonation. The possible cause may have been misalignment of the spitback in the fuze body during assembly. Another possible cause of failure may have been the use of an RDX load of questionable structural integrity. The 40 rounds constructed for Test Series No. 2 used loaded cups selected from the first lot of 250 loaded cups received 31 August 1973 from Milan Army Ammunition Plant. Of the 250 cups then received, only 50 were considered acceptable because of cracks and voids prevalent in the RDX of the remaining 200. Although 50 loaded cups were believed acceptable at the time of selection, these were not of a quality comparable to 200 rounds received later on 29 October 1973. These last-received cups were used for the remainder of the test program.
- 4.3.2.3 Figures 8 through 12 are graphs of the test data recorded in Table III. These data are a function of the incendiary slug volume. Although there is no single configuration that can be considered superior to all others for all parameters investigated, Company engineers believe that the overall most favorable performance was obtained with a zirconium slug having a diameter of 0.4 CD, a length of 0.5 CD, and they believe that the results were particularly favorable with regard to residual penetration (as shown in Figure 11).
- 4.3.2.4 A showering of burning incendiary particles was observed visually in the penetration tests. At times the burning particles started grass fires on the perimeter of the test arena. The number of burning particles and frequency of grass fires increased with an increase in the volume of the incendiary slug. It is evident from several observations that these incendiary particles spraying and ricocheting inside a vehicle would enhance effectiveness of the 40-mm round by causing ignition of flammable material within a target (e.g., a tank, APC or similarly enclosed vehicle) and would most certainly create a hazardous environment for personnel.
- 4.3.3 Test Series No. 3 -- Determination of Optimum Incendiary Material
- 4.3.3.1 The Third Test Series (11 tests) compared the misch metal and zirconium incendiary materials for effectiveness. Eight rounds were fired which were assembled with misch metal incendiary slugs having the configuration deemed optimum in the Series No. 2 tests (0.4 CD diameter by 0.5 CD length): three penetration tests, four pressure-temperature tests, and one photo-documentation test. Three zirconium incendiary rounds of the same configuration were fired: two pressure-temperature tests and one photo-documentation test. The tests involving zirconium incendiary were repeated from Test Series No. 2 as an assurance

of eliminating all possible environmental variation which may have affected test results. Series No. 3 test results were used as a basis for establishing zirconium as the optimum incendiary material. The results are presented in Table IV on the following page.

- 4.3.3.2 Giving consideration only to the first two misch metal pressure-temperature test results, as presented in Table IV, made it difficult to accurately determine the optimum incendiary material. Because of difficulty with instrumentation (see Subsection 4.4), Chamberlain engineers found it necessary to fire additional rounds having misch metal incendiary. Test Number 3M-B3 had exceptionally high readings in peak pressure, thermal output, and butterfly gage deflection. Since the magnitude of these readings is so great compared to those of other rounds tested having the same incendiary configuration, these data cannot be regarded as predictable and hence, not typical. The final confirmation of the optimum incendiary material was made by evaluating the results of the photo-documentation tests.
- 4.3.3.2.1 Photograph Nos. C-2871 thru C-2874 on Pages 33 through 39 show selected frames from the high-speed films exposed during the photo-documentation tests. It is noteworthy here that Series 4 photo-documentation test results are included in these photos. This paragraph concerns only the first three: Serial Nos. 11-D1, 3M-D1, and 3Z-D1. In Photo No. C-2871 little difference is evident among the four frames. In Photo Nos. C-2872 and C-2873, the modified rounds obviously have outperformed the standard test item, while in Photo No. C-2874, the zirconium item appears superior with clear evidence of incendiary particles still following the jet at 7.4 ms after initiation. The zirconium particles seem to be fewer in number but of larger size than the misch metal particles. Further analysis of the film shows that the fireball from the standard item dissipates in approximately 70 milliseconds, that of the item modified with misch metal dissipates in 10 milliseconds, and the fireball from the zirconium-modified item dissipates in approximately 75 milliseconds.
- 4.3.3.3 Evaluation of all results from Test Series No. 3 leads to the conclusion that zirconium is the optimum incendiary material of those investigated for this task. This conclusion is based on the following performance statistics (comparison of the modified round having zirconium incendiary is made to the standard M433 Round):

- Minimum degradation of penetration: 15%
- 110% increase in peak pressure
- 65% increase in thermal output
- 60% increase in residual penetration
- Superior burn duration made evident by photo-documentation tests.

4.3.4 Test Series No. 4 -- Determination of Optimum Incendiary Configuration

4.3.4.1 The Fourth Test Series (14 firings) was conducted to evaluate the desirability of tapering the interior surface of the incendiary slug as described previously in Paragraph 4.2.1.2. Six rounds were fired assembled with zirconium incendiary having the optimum external configuration (per Test Series No. 2) and a tapered internal configuration: three penetration tests and three pressure-temperature tests. Eight rounds assembled with misch metal incendiary of the same configuration also were tested: five penetration tests, two pressure-temperature tests, and one photo-documentation test. Both types of incendiary materials were used in this Test Series to verify the conclusions on optimum incendiary material derived from Test Series No. 3. These test results were used as a basis for establishing that the tapered internal configuration offers no measurable increase in effectiveness, and for confirming the choice of zirconium as the optimum incendiary material. Results of these tests are presented in Table V on Page 41.

(Text Continued on Page 42)

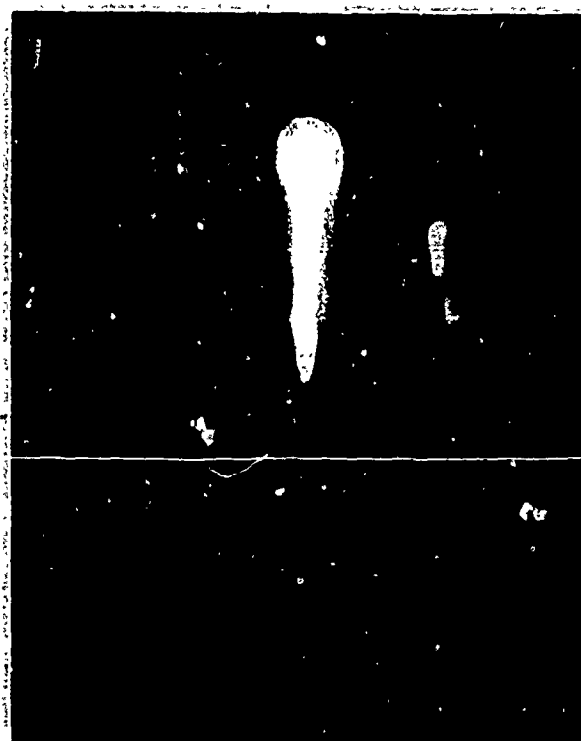
TABLE IV
RAW TEST DATA
SERIES 3
DETERMINATION OF OPTIMUM INCENDIARY MATERIAL

TEST SERIAL NO.	PENETRATION DEPTH (in.)	TEST SERIAL NO.	PEAK PRESSURE (PSI)	THERMAL OUTPUT (MV)	RESIDUAL PENETRATION (in.)	BUTTERFLY GAGE DEFLECTION	
						.063 THK. (in.)	.080 THK. (in.)
3M-P1	3.50	3M-B1	N.D.	N.D.	0.88	1.73	0.88
3M-P2	3.06	3M-B2	N.D.	N.D.	0.90	2.06	0.82
3M-P3	2.75	3M-B3	54.0	4.00	0.98	Saturated	3.45
		3M-B4	30.0	1.65	1.25	2.04	0.95
		3Z-B1	40.0	1.80	1.00	3.17	2.50
		3Z-B2	25.0	2.20	1.30	1.81	0.87

N.D. Designates no data recorded



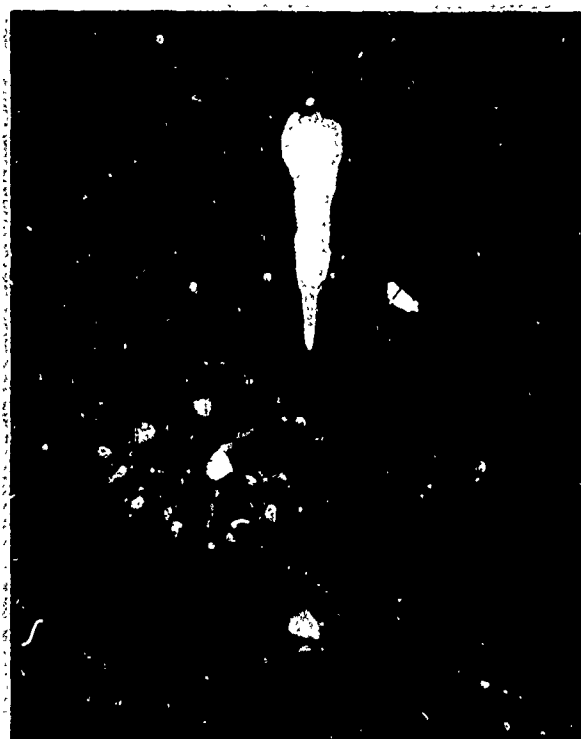
Standard Round
Serial No. 11-D1



Misch Metal Slug
Serial No. 3M-D1



Zirconium Slug
Serial No. 3Z-D1



Tapered I. D. Misch Slug
Serial No. 4M-D1

PHOTO NO. C-2871

PHOTO-DOCUMENTATION TESTS

TIME: 0.7 MS

-33-

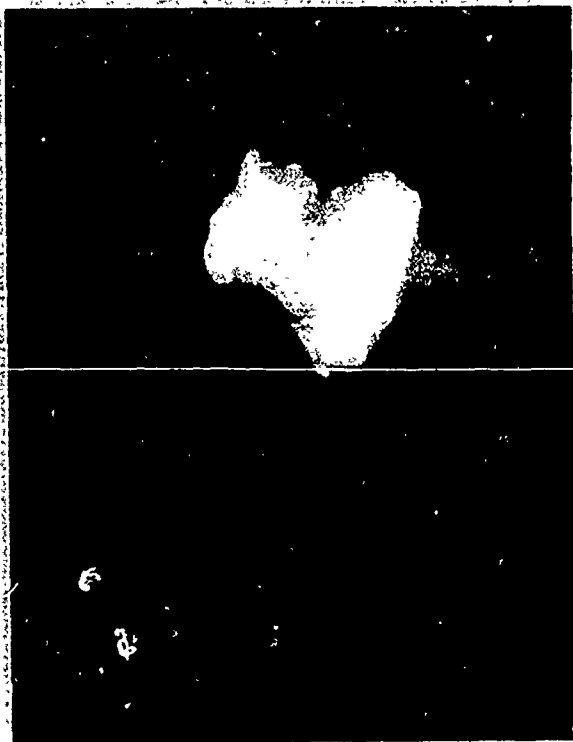
UNCLASSIFIED



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UNCLASSIFIED



**Standard Round
Serial No. 11-D1**



**Misch Metal Slug
Serial No. 3M-D1**



**Zirconium Slug
Serial No. 3Z-D1**



**Tapered I. D. Misch Slug
Serial No. 4M-D1**

PHOTO NO. C-2872

PHOTO-DOCUMENTATION TESTS

TIME: 3.7 MS

-35-

UNCLASSIFIED

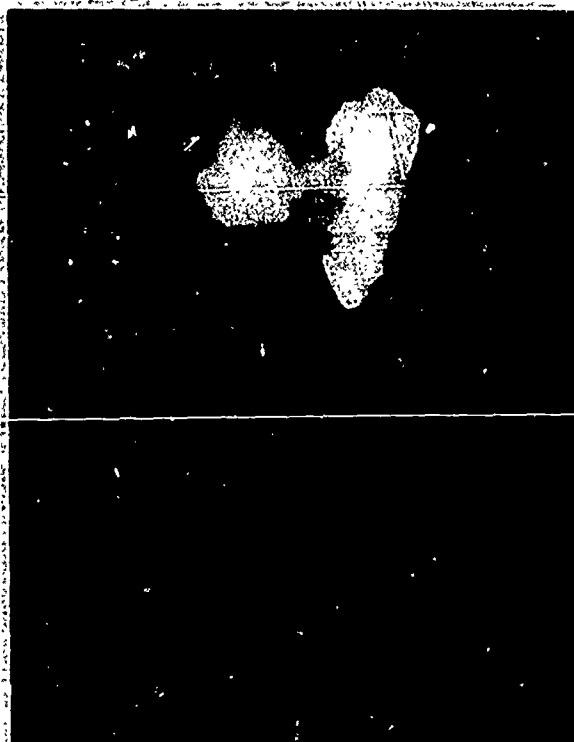
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**Standard Round
Serial No. 11-D1**



**Misch Metal Slug
Serial No. 3M-D1**



**Zirconium Slug
Serial No. 3Z-D1**



**Tapered I. D. Misch Slug
Serial No. 4M-D1**

PHOTO NO. C-2873

PHOTO-DOCUMENTATION TESTS

TIME: 5.5 MS

-37-

UNCLASSIFIED

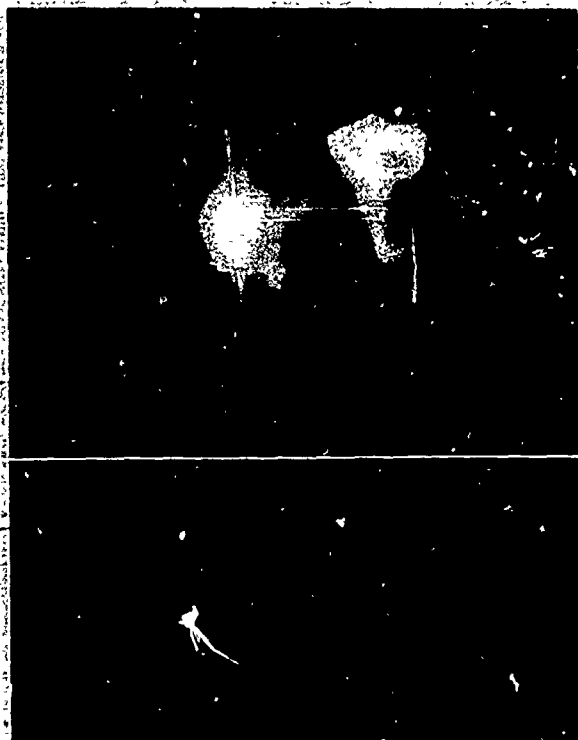
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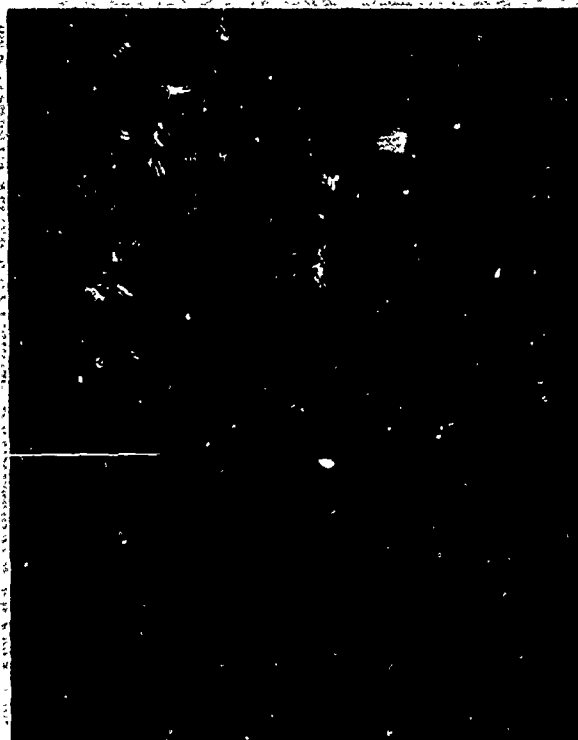
Chamberlain

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**Standard Round
Serial No. 11-D1**



**Misch Metal Slug
Serial No. 3M-D1**



**Zirconium Slug
Serial No. 3Z-D1**



**Tapered I. D. Misch Slug
Serial No. 4M-D1**

PHOTO NO. C-2874

PHOTO-DOCUMENTATION TESTS

TIME: 7.4 MS

-39-

UNCLASSIFIED

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TABLE V

RAW TEST DATA
SERIES 4
DETERMINE OPTIMUM INCENDIARY
INTERNAL CONFIGURATION

SERIAL NO.	PENET. DEPTH (in.)	TEST SERIAL NO.	PEAK PRESSURE (PSI)	THERMAL OUTPUT (MV)	RESIDUAL PENET. (in.)	BUTTERFLY GAGE DEFLECTION	
						.063 THK. (in.)	.080 THK. (in.)
4M-P1	2.70	4M-B1	38.0	2.70	.74	3.44	2.70
4M-P2	2.50	4M-B2	45.0	2.15	1.12	3.32	2.92
4M-Pe	3.50	4Z-B1	Low Order	-	-	-	-
4M-P4	3.30	4Z-B2	Low Order	-	-	-	-
4M-P5	3.10	4Z-B3	30.0	2.20	1.04	2.20	1.18
4Z-P1	3.10						
4Z-P2	3.40						
4Z-P3	Low Order						

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- 4.3.4.2 The misch metal tapered slug showed marginal improvement in peak pressure and thermal output probably attributable to an increase in the incendiary volume from a 0.080-cubic-inch straight I.D. slug to a 0.094-cubic-inch tapered I.D. slug. This represents an increase in the mass of incendiary material of approximately 15%. Rounds having the misch metal tapered I.D. slug yielded a decrease in penetration in the penetration tests and in residual penetration in the pressure-temperature tests. Average penetration of three inches was achieved in static test firings using zirconium uniform incendiary I.D. slugs. This penetration was considered marginally acceptable, because penetration of 2.5 inches is required by the contract. Therefore, Chamberlain does not believe that a trade for an increase of peak pressure and thermal output obtainable from the tapered I.D. incendiary is worth the trade for the further degradation of penetration which would result. This conclusion is substantiated further by the results of the photo-documentation tests. It is noteworthy that in Photo Nos. C-2872 and C-2873 there is less visible follow-through from the misch metal tapered I.D. round than from the misch metal straight I.D. round.
- 4.3.4.3 No photo-documentation tests were conducted with rounds assembled with the zirconium tapered I.D. slug because of the initiation problem previously experienced in the penetration and pressure-temperature tests. The low-order detonation problem encountered is thought to be attributable to the coarse texture of the surface of the tapered I.D. portion of the zirconium slug. Voids in the surface may have absorbed and/or deflected the spitback particles/gases sufficiently to cause inadequate RDX initiation and hence low order detonation.
- 4.3.4.4 The 1/8-inch mild steel witness plate (located approximately 8 1/2 feet from the 6-inch initial target plate) was perforated with approximately twenty holes up to 1/4 inch in diameter, clustered in a 10-inch circle. No significant difference in damage to the witness plates was observed among the four photo-documentation tests.
- 4.3.4.5 Based on the results of Test Series No. 4, Chamberlain engineers believe that use of the tapered internal configuration in the misch metal slug does not offer any appreciable increase in round effectiveness. In addition, the tapered design does not readily lend itself to mass producibility as does the design specifying a uniform (cylindrical configuration) I.D.

4.3.5 Test Series No. 5 -- Evaluation of Penetration Performance
Versus Standoff

4.3.5.1 The Fifth Test Series consisted of six firings with modified hardware as determined optimum through the previous four series of tests. This series was conducted to produce the necessary data to complete a penetration versus standoff relationship. Three penetration tests were conducted with a standoff of 2 CD and three were conducted with a standoff of 3 CD. A 5 CD standoff test was not performed because of the poor results obtained in Test Series No. 1 with that standoff distance. Data collected from this Test Series (see Table VI, below), along with results from Test Series No. 1, were used to generate a curve (Figure 13 on the following page) depicting Penetration versus Standoff.

TABLE VI
RAW TEST DATA
SERIES 5
PENETRATION VERSUS STANDOFF

<u>TEST SERIAL NO.</u>	<u>PENETRATION DEPTH (in.)</u>
52-P1	3.0
52-P2	2.60
52-P3	2.65
53-P1	3.00
53-P2	2.00
53-P3	2.25

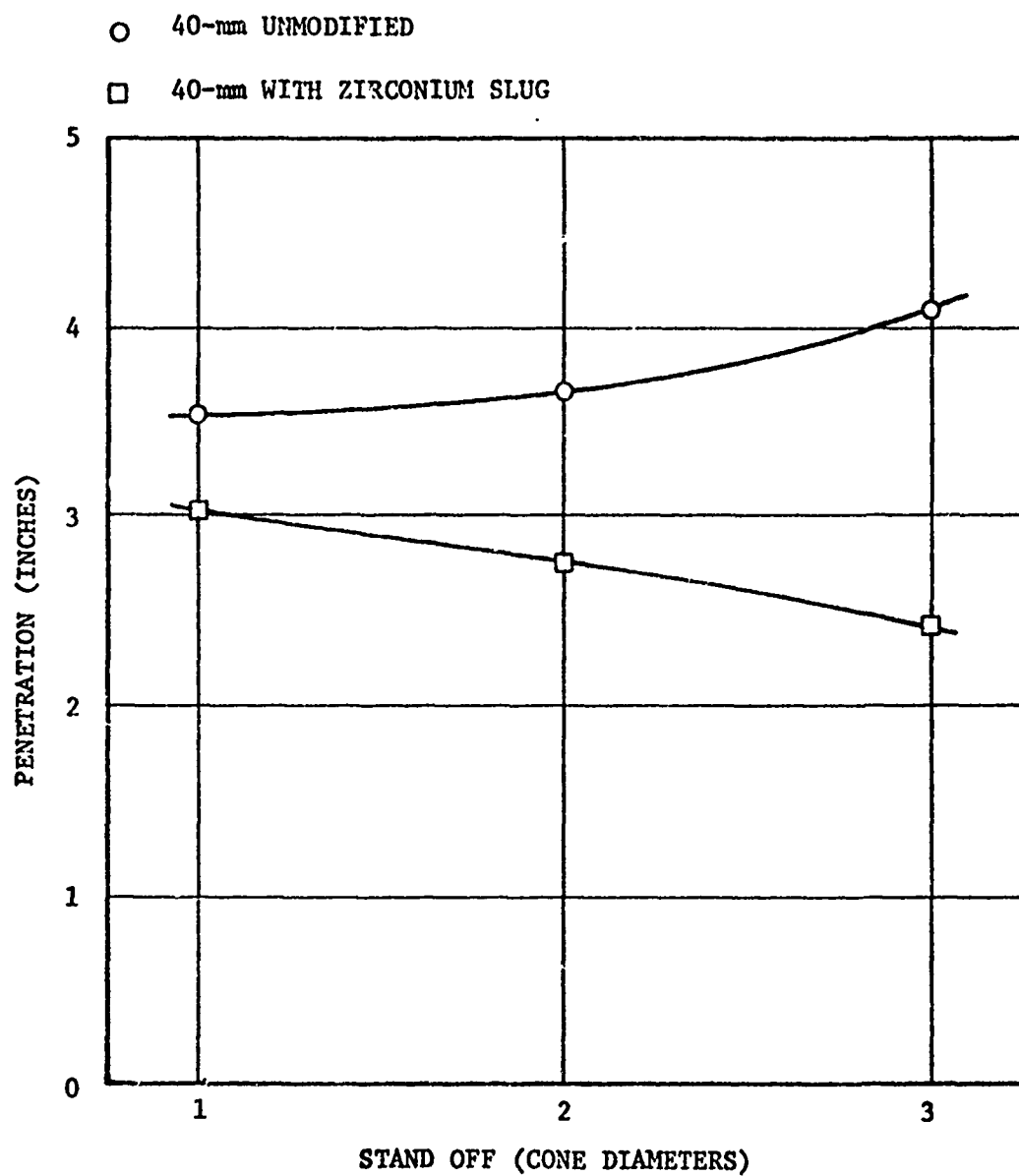


Figure 13
PENETRATION AS A FUNCTION OF STANDOFF

4.3.5.2 The Penetration versus Standoff Curve presented in Figure 13 on the previous page shows two clear patterns:

1. Overall penetration performance of the modified round having the tubular zirconium follow-through slug was less than that of the standard M433 Round within the limits of the standoff shown.
2. Unmodified (standard M433) round penetration varied directly with standoff distance while the penetration of the modified round varied inversely with standoff distance, again within the standoff limits shown.

4.4 Test Program Evaluation

4.4.1 The Test Program provided not only the means by which to select the optimum incendiary material and configuration from those considered, but it also demonstrated the superiority of the incendiary items over the control items, with the exception of penetration. Design feasibility was demonstrated from the standpoint of terminal effects, and also with regard to the ease of manufacture and loading of the hardware.

4.4.2 The conclusions derived from the Test Program are based on engineering judgment as well as on specific test data. The small number of tests (three penetration tests per design, two pressure-temperature tests per design and one photo-documentation test per design) makes it difficult to reach conclusions with a large degree of confidence. Selection of optimum designs is based on performance in all tests, including visual assessment of residual incendiary effects.

Because a reduction of the explosive head height from 0.715 inch to 0.333 inch resulted from adding the incendiary slug to the shaped charge liner, the amount of variation in explosive head height sharply influenced the performance of the modified round. This head height is marginal and Company engineers believe that better performance could be achieved by moving the liner forward, thus increasing explosive head height and reducing the volume lost due to the addition of the incendiary slug. Because degradation in performance is directly proportional to HE loss, performance should be enhanced substantially by increasing both head height and volume of HE.

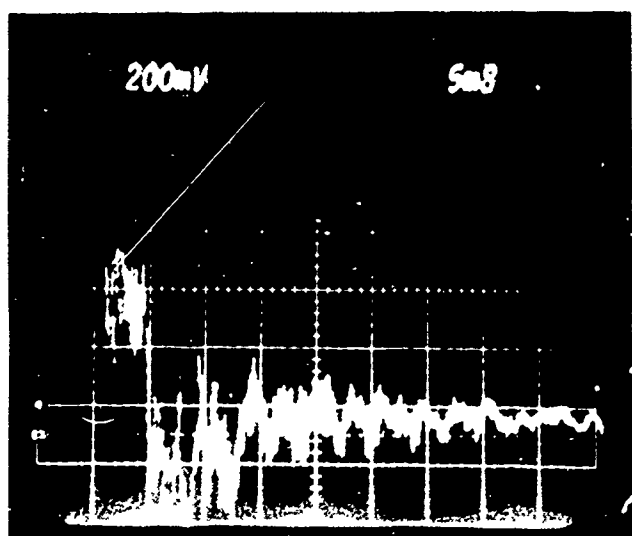
Depth of penetration was the only parameter with which degradation from the performance of the standard M433 round was experienced. Chamberlain engineers believe that further investigation of incendiary configuration will correct this problem. As shown in Figure 9, rounds assembled with the 0.3 CD diameter by 0.4 CL length incendiary slug performed as well in terms of penetration as the standard (control) round but little increase in pressure

and temperature was experienced due to the small incendiary slug volume (0.027 cubic inches). Again, if the liner can be moved forward approximately 1/8 inch, it is expected that no degradation of penetration performance (when compared with the standard round) would occur with use of an incendiary slug 0.3 CD diameter by 0.5 CD length. At the same time, they expect that use of an incendiary slug having these dimensions will result in enhancement of inside-the-target pressure and temperature attributable to the increase in volume of incendiary material.

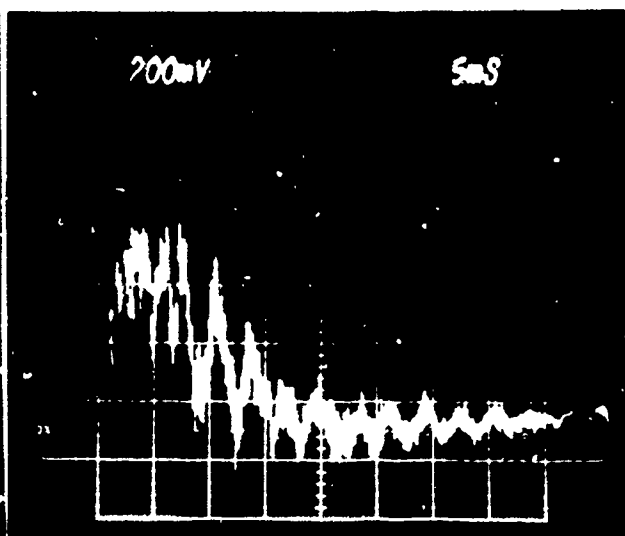
Picatinny Arsenal Drawing No. 8886374, Cup and Liner Loading Assembly, required the explosive head height to be 0.280 + 0.050 inches and perpendicular to the I.D. of the skirt and within 0.010 inch. As much as 0.036-inch variation in explosive height was found in rounds received from Milan Army Ammunition Plant. Thus the liner and slug were not concentric to the I.D. of the cup and skirt, nor were they perpendicular to the designated target. It is expected that this deviation from print would have an adverse effect on performance and would (in part) explain the variation in test results, particularly variations in penetration.

4.4.3

Some instrumentation problems were experienced. In a few tests, one or more sensors failed, necessitating additional testing. Determination of the true impulse from the pressure-time data was hindered by the multiple-pulse nature of the recorded signal which possibly is caused by ringing of the chamber. Most traces consisted of a pulse curve having a duration of 5 to 20 milliseconds followed by several other pulses of varying duration. Typical pressure transducer curves may be seen in Photo No. 10197 on the following page. Each curve consisted of 0.15-millisecond duration spikes, which are comprised of recorded electronic noise. The average of these spikes produced a curve which was regarded as the actual pressure. This condition was attributable in part to distortion of the charge generated by the rapid displacement of the micro-dot cable which carries the monitored signal from the pressure transducers to the recording device. The total impulse calculated by integration of the area under this pressure pulse curve is significantly lower than the true total impulse as predicted analytically and indicated by butterfly gage deflection. Consequently, only peak pressure and duration of the positive pressure pulse curve are used for comparison purposes. This shows that the actual impulses for the incendiary tests are higher than those for the non-incendiary tests and the duration for rounds having zirconium incendiary was longer than for those rounds assembled with misch metal incendiary. Evidence of this appears not only in the greater duration of the pressure curve, but also through the observable duration of the fireball in the photo-documentation film.

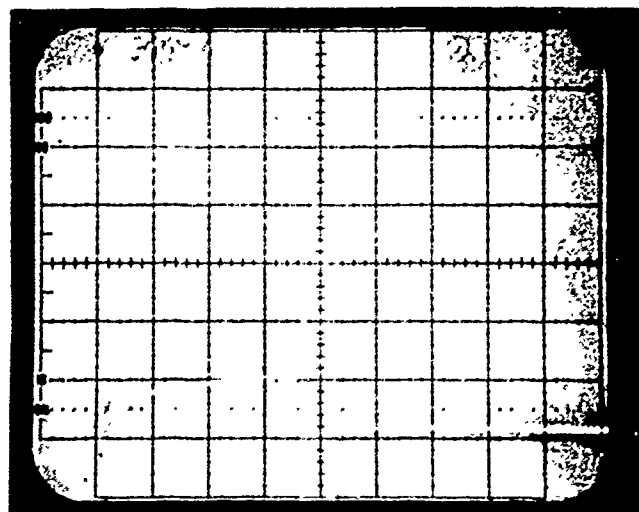


Standard Round
Serial No. 11-B6

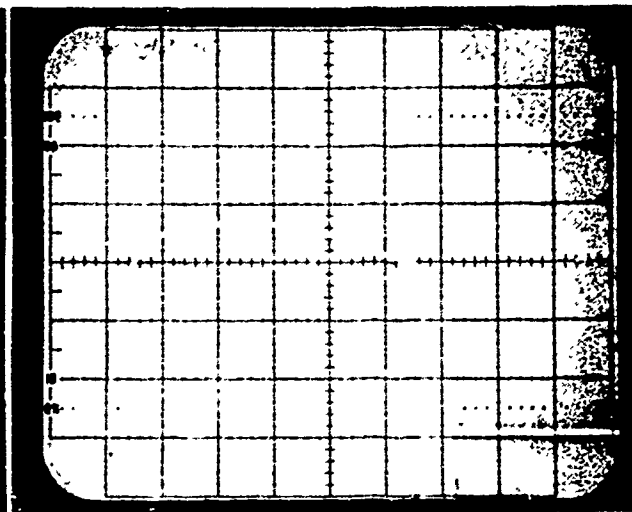


Zirconium Slug
Serial No. 32-B1

PRESSURE TRANSDUCER OUTPUT
10 psi/cm; 5 ms/cm



Standard Round
Serial No. 11-B6



Zirconium Slug
Serial No. 32-B1

THERMOCOUPLE OUTPUT
500 mV/cm; 2 sec/cm

PHOTOGRAPH NO. 10197

- 4.4.4 Peak pressure data derived from the mechanical butterfly gages revealed reasonable correlation with data from the electronic transducers for the incendiary items. The butterfly gages provided very reliable with uniform results, and thus were an excellent mechanism for comparison of the various designs. Although the butterfly gages are valuable for purpose of comparison, their utility in providing absolute values of pressure and impulse are questionable. For this reason, the butterfly gage results were used as a tool for comparison between designs in terms of deflection, and not to obtain absolute pressure and impulse values.
- 4.4.5 Thermal output was measured with a chromel/alumel thermocouple as described previously. Typical thermocouple output traces may be seen in Photo No. 10197 on Page 47 . The response time (20 ms) of this system proved to be slow. Consequently, the recorded outputs represent total temperature rise of the entire system - the box, target stack and air - rather than the transient temperature rise directly attributable to the dynamic presence of the incendiary slug. Because the entire system was massive (several hundred pounds), temperature increases were not large. The outputs reported herein are presented in millivolts for purposes of comparison rather than actual changes in temperature. Figure 14 on the following page presents thermocouple output as a function of temperature rise above ambient for this system. While the absolute temperature values may not be accurate, the recorded data were uniformly predictable and offered an adequate means of comparing the performance of test hardware of differing designs.
- 4.4.6 In summary, the results of the tests are valid in that they provide a basis for comparison of specified designs and a means for selection of the optimum incendiary material and configurations. In addition, the data is useful in determining a qualitative increase in lethality of the M433 Round incorporating the incendiary follow-through technique.

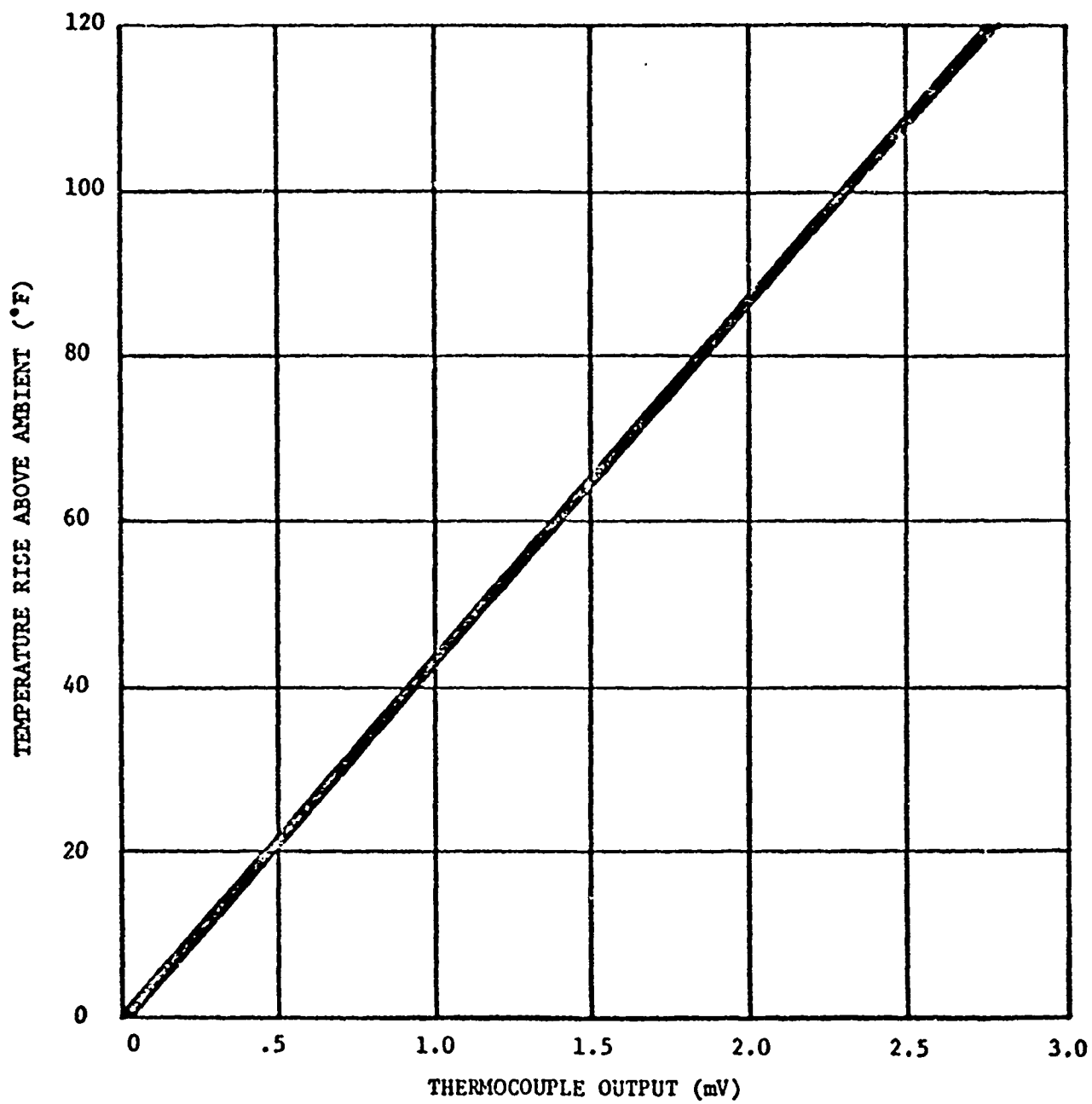


Figure 14
TEMPERATURE RISE ABOVE AMBIENT VERSUS THERMOCOUPLE OUTPUT

FINAL TECHNICAL REPORT
CONTRACT DAAA21-73-C-0476

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 The following criteria comprise the basis for evaluation in determining optimum incendiary configuration and material (listed in descending order of importance):

- Minimum degradation to penetration
- Improvement of post-armor effectiveness
- Residual penetration capability

5.1.2 Within the limits set by the Scope of Work, the following round having incendiary enhancement was deemed optimum:

Incendiary Slug Material:	Sponge Carconium
Incendiary Slug Configuration:	Tubular, having I.D. of uniform diameter the same as the spitback hole in the shaped charge liner of the standard round.
Incendiary Slug Width:	0.4 CD
Incendiary Slug Length:	0.5 CD
Munition Standoff:	1.0 CD

5.1.3 This program demonstrated that incendiary follow-through effects are achieved by placing an incendiary slug at the apex of a shaped charge liner. Benefits derived from the inclusion of this incendiary material include:

- Increase in target residual penetration.
- Increase in temperature rise (enclosed target).
- Increase in positive pressure pulse (enclosed target).
- Introduction of burning particles into enclosed target (to ignite flammable materials).

5.1.4 This particular method of incorporating incendiary into a shaped charge weapon (placement of an incendiary slug at the cone apex) possesses the following benefits.

- Ease of manufacture (incendiary).
- Ease of hardware modification (to utilize the incendiary).
- Ease of HE loading
- Ability to include a significant volume of incendiary material within the warhead.
- Improvement in terminal effectiveness for ignition sensitive targets.

5.1.5 The test results indicate that the shaped charge/incendiary follow-through technique evaluated in this program shows substantial promise as a method for increasing the terminal effectiveness of shaped charge weapons. However, Chamberlain believes that parameters remain to be investigated. These include:

- Explosive head height (beyond incendiary slug)
- Confinement of the shaped charge.
- Effects on fragmentation characteristics.
- Flash intensity and duration (inside the target).
- Oxygen depletion (inside the target).
- Post-armor effects.
- Incendiary material and configuration.
- Effect of terminal impact and/or spin on weapon function.

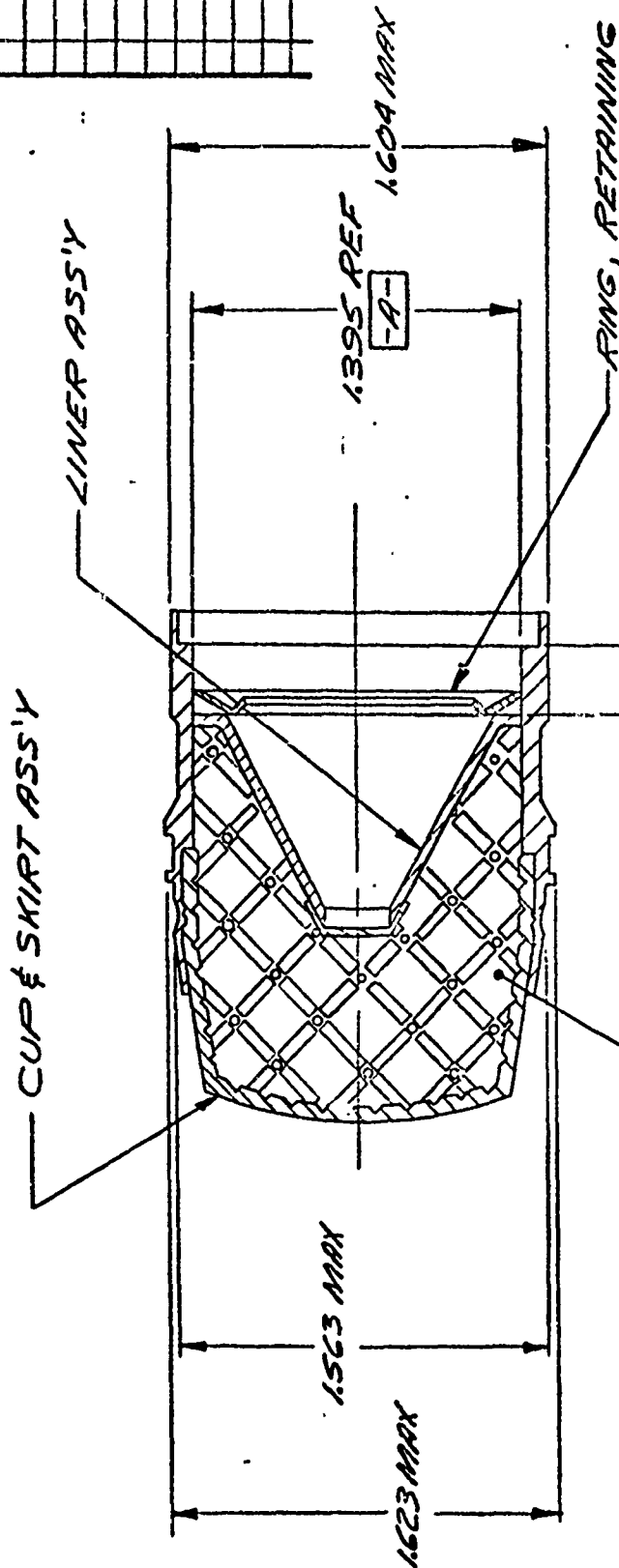
5.2 Recommendations

5.2.1 This program has demonstrated the feasibility of assembling the M433 Round with an incendiary slug to enhance post-armor effectiveness, but at the cost of degradation in penetration. With a follow-on effort, Chamberlain can restore the penetration capability now possessed by the standard, unmodified round, while retaining the post-armor effectiveness obtained with modified test hardware during this initial effort.

5.2.2 Chamberlain recommends pursuit of the incendiary follow-through technique in a program of extended scope beyond the current effort. Such a program would provide sufficient data to permit the selection of a cost-effective incendiary configuration and composition that will substantially enhance the terminal effectiveness of projectile, 40-mm, HEDP, M433.

A P P E N D I X

1. Engineering Drawings
2. Material Specification for Zirconium Particles.

[illegible]

NOTE 2

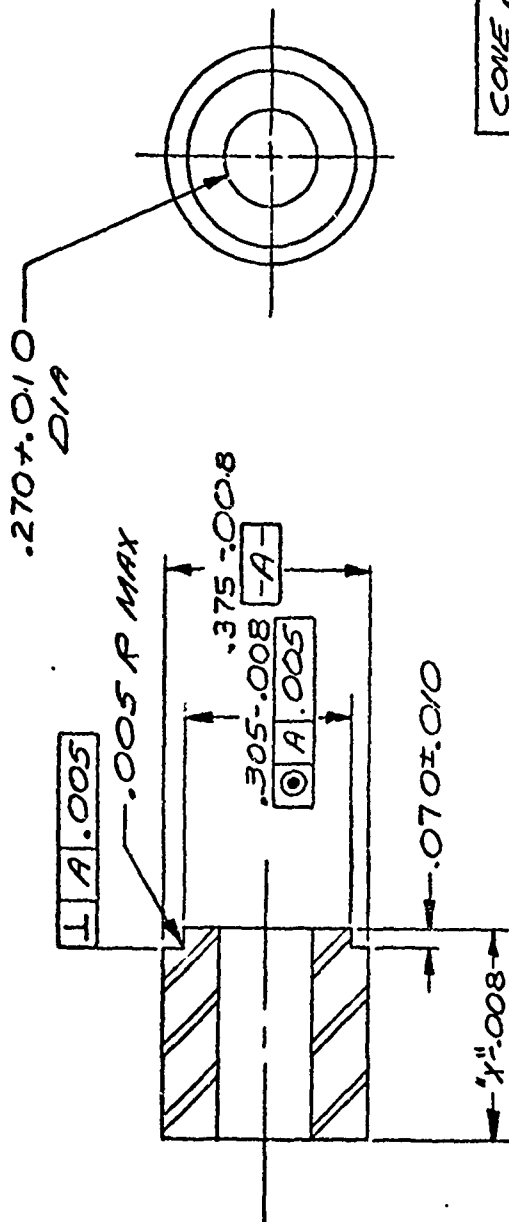
NOTES:

1. SPEC MIL-A-2550 & MIL-C-50872
APPLY
2. LOAD WITH APPROX 45.0 GRAMS,
POX, DWG 9276547. SPECIFIC
GRAVITY 1.6 MIN.
3. UNTOLEERANCED DIM. NEEDED NOT
BE GAGED.
- A LINER ASSY, DWG 9276545, SHALL
BE USED TO COMPLETE FINAL
CONSOLIDATION OF THE POX CHARGE.

PART NO. 8886374

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME <i>CUP & LINER</i> LOADING ASS'Y MATERIAL <i>SEE DETAILS</i>	NAME <i>CUP & LINER</i> LOADING ASS'Y MATERIAL <i>SEE DETAILS</i>	DRAWN <i>D.P.B.</i>	DATES <i>7/19/27</i>
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				SCALE <i>2/1</i>	
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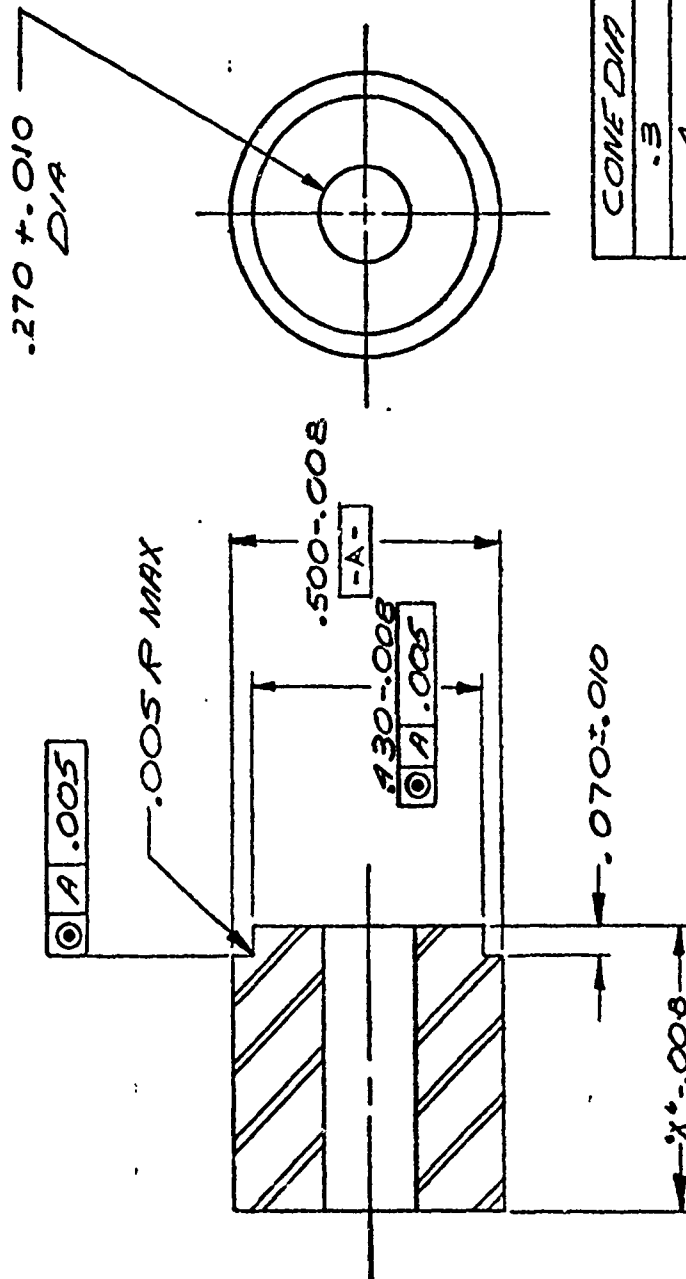
COME DIA	"X" 42/1074
.3	.375
.4	.500

NOTES:

1. INTERPRET DWG IN ACCORDANCE WITH MIL-STD-100.
2. MATERIAL, INCENDIARY: MISC. OR ZIRCONIUM.
3. REMOVE ALL BURRS AND SHARP EDGES .02 MAX.

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	.3 CD DIA. INCENDIARY SLUG MATERIAL SEE NOTE 2				DRAWN	DATE
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CONC DIA	"X" LENGTH
.3	.375
.4	.500
.5	.625

i INTERPRET DWG IN ACCORDANCE

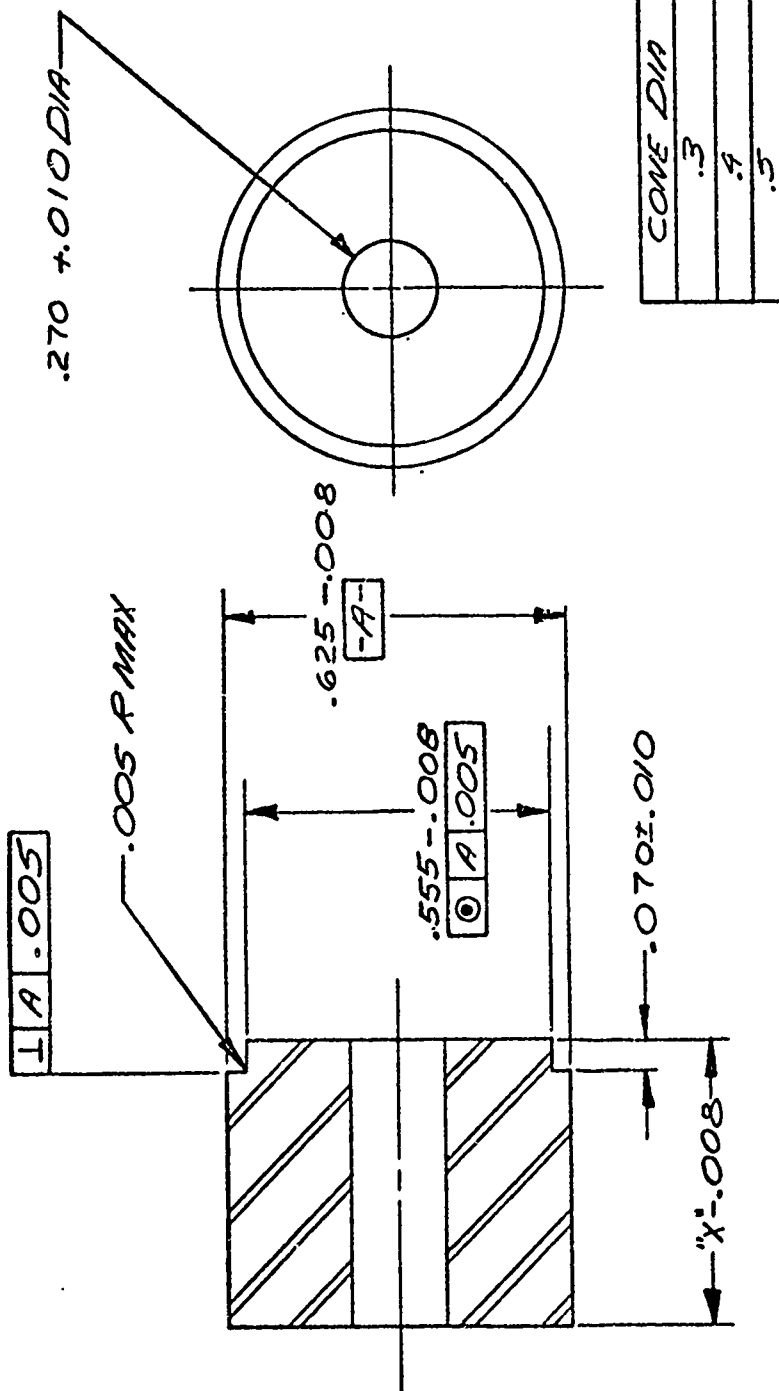
WITH MK-STD-100.
2. MATERIAL, INCENDIARY: MICH
OR ZIRCONIUM.

3. REMOVE ALL BURRS AND SHARP EDGES .02 MAX.

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	MATERIAL SEE NOTE 2		CHECKED J.M.	DATE 4/15/53
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	FRAC.	SCALE 4/1		DATE OF PRINT
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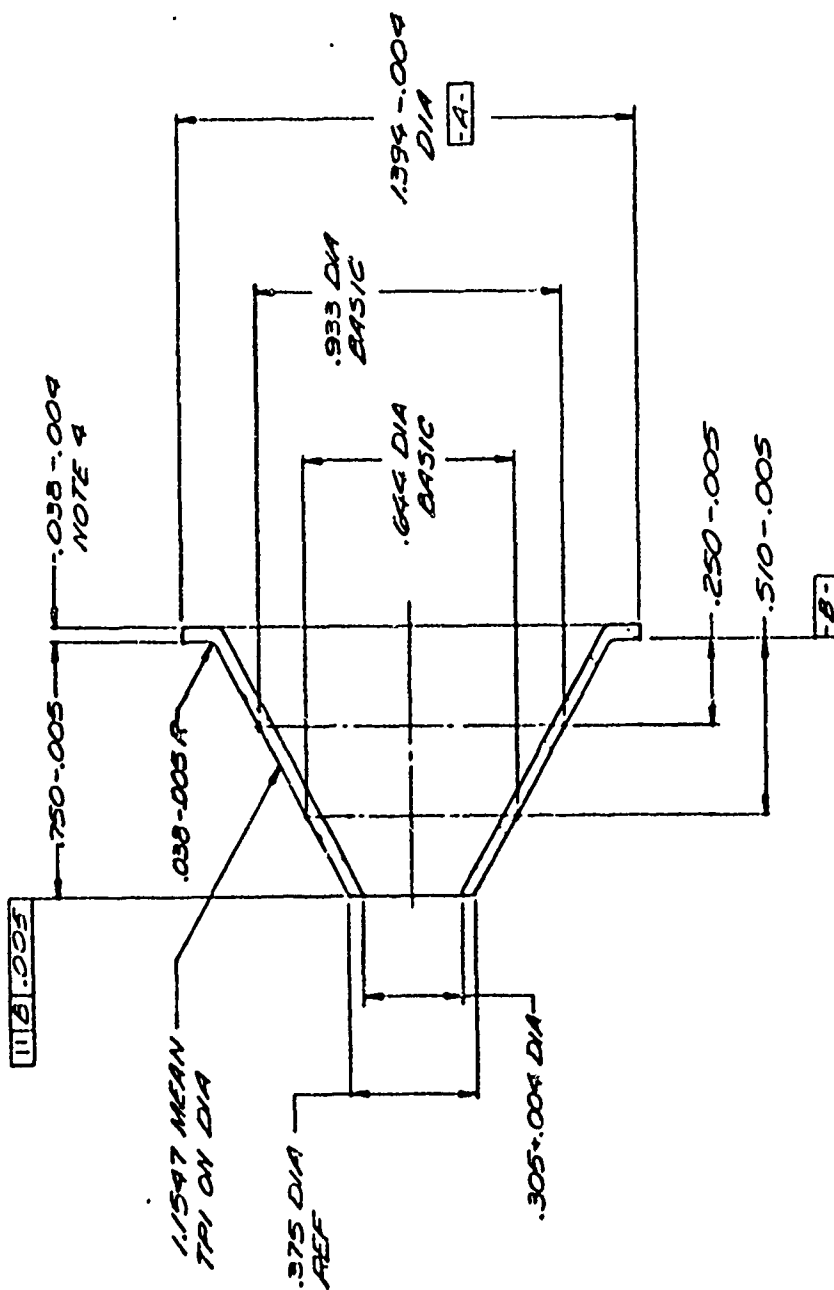
529.	5.
005.	4.
375.	3.
X-LENGTH	CONC DIA

NOTES:

1. INTERPRET DWG IN ACCORDANCE WITH MIL-STD-100.
2. MATERIAL, INCENDIARY: M15CH OR ZIRCONIUM
3. REMOVE ALL BURRS AND SHARP EDGES .02 MAX.

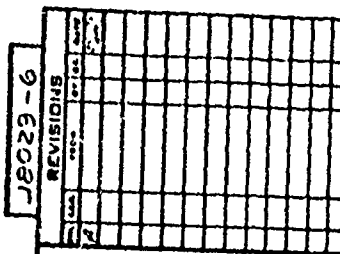
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			SCALE 4/1		
FRAC.	DATE OF PRINT				
.000	<div> <div>CHAMBERLAIN</div> <div>MANUFACTURING CORPORATION</div> <div>WATERLOO, IOWA</div> </div>				
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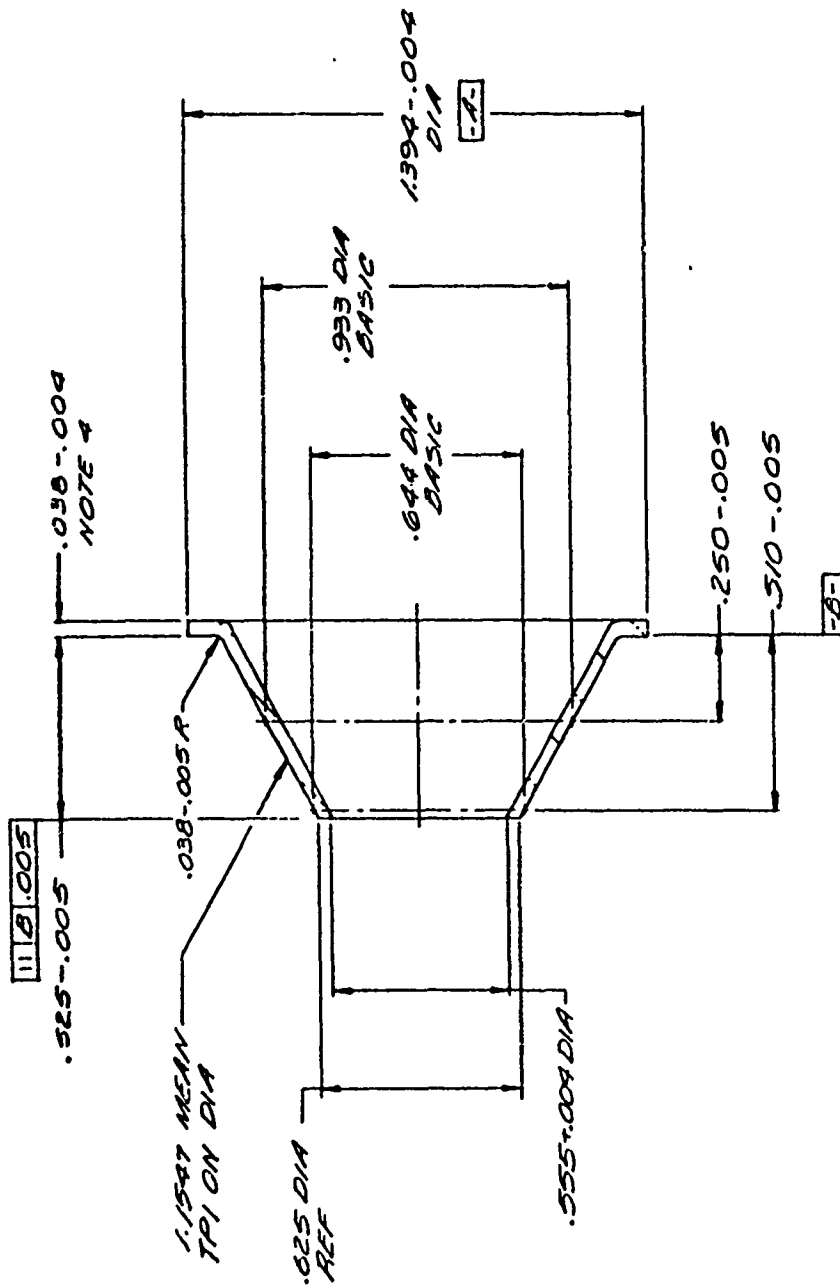


- NOTES:
1. SPEC MIL-A-2550 AND MIL-C-50870 APPY.
 2. MATERIAL: COPPER ANNEALED ASTM
 3. B152 COPPER NO. 102 OR 110.
 4. REMOVE ALL BURRS AND SHARP EDGES
 5. VARIATION IN WALL THICKNESS
 6. MEASURED NORMAL TO SURFACE
 7. NOT EXCEED .003 IN ANY TRANSVERSE
 8. PLANE.

[illegible]

[illegible]

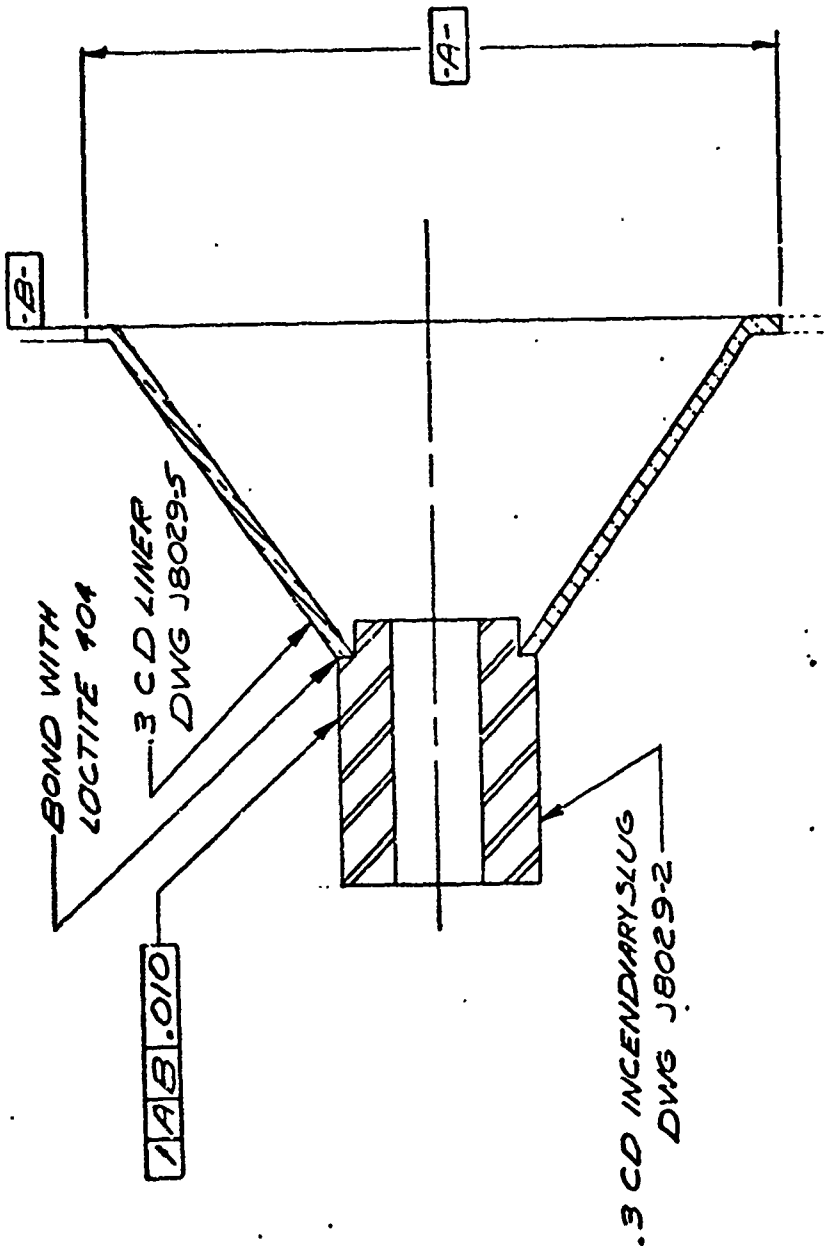
4-62081



- NOTES:
1. SPEC MIL-A-2550 AND MIL-C-50870 APPL.
 2. MATERIAL: COPPER, ANNEALED ASTM B152 COPPER NO. 102 OR 110.
 3. REMOVE ALL BURRS AND SHARP EDGES.
 4. VARIATION IN WALL THICKNESS MEASURED NORMAL TO SURFACE NOT TO EXCEED .003 IN ANY TRANSVERSE PLANE.

UNLASHED AND UNPAID UNPAID CARRIER DATE	.5CD LINER		DATE 20-7-73	DATE 20-7-73	DATE 20-7-73
PROG.	SEE NOTE E		DATE 20-7-73	DATE 20-7-73	DATE 20-7-73
DATE	CHAMBERLAIN		DATE 20-7-73	DATE 20-7-73	DATE 20-7-73
DATE	MANUFACTURING		DATE 20-7-73	DATE 20-7-73	DATE 20-7-73
DATE	UNPAID CARRIER		DATE 20-7-73	DATE 20-7-73	DATE 20-7-73
DATE	UNPAID CARRIER		DATE 20-7-73	DATE 20-7-73	DATE 20-7-73

REVISIONS

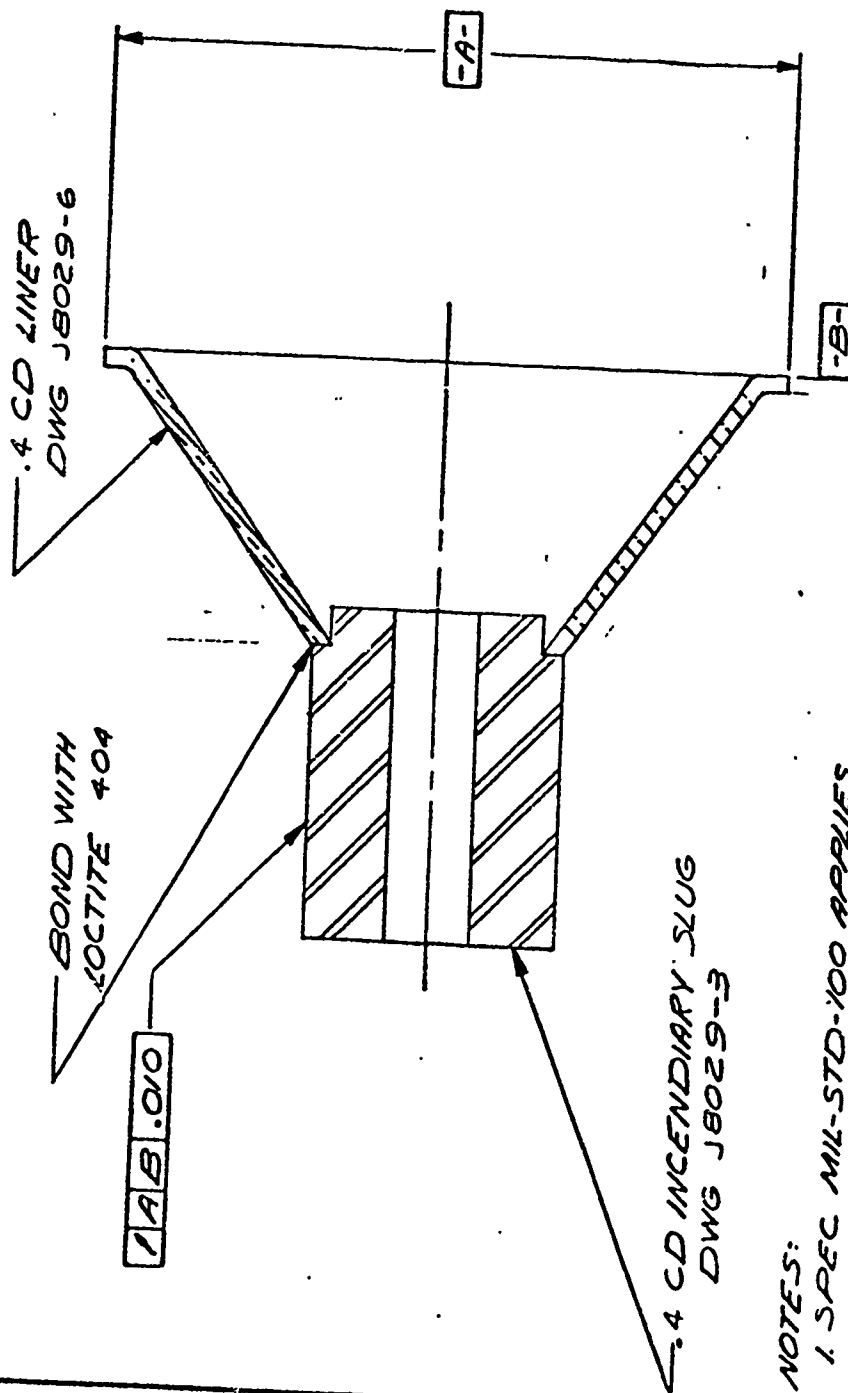
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NOTE:
SPEC M14-STD-100 APPLIES:

1. SPEC MIL-STD-100 APPLIES.

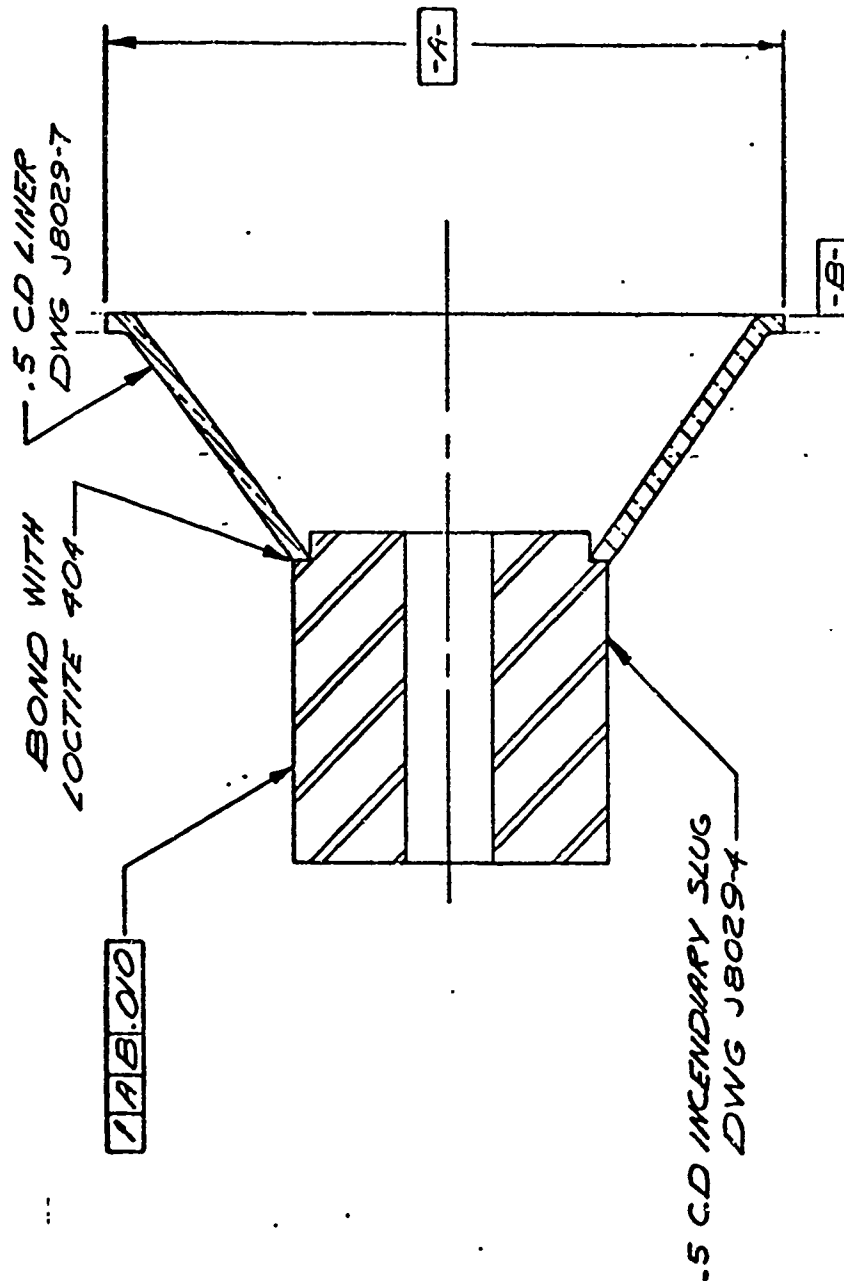
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[illegible]

NOTES:
1. SPEC MIL-STD-100 APPLIES.

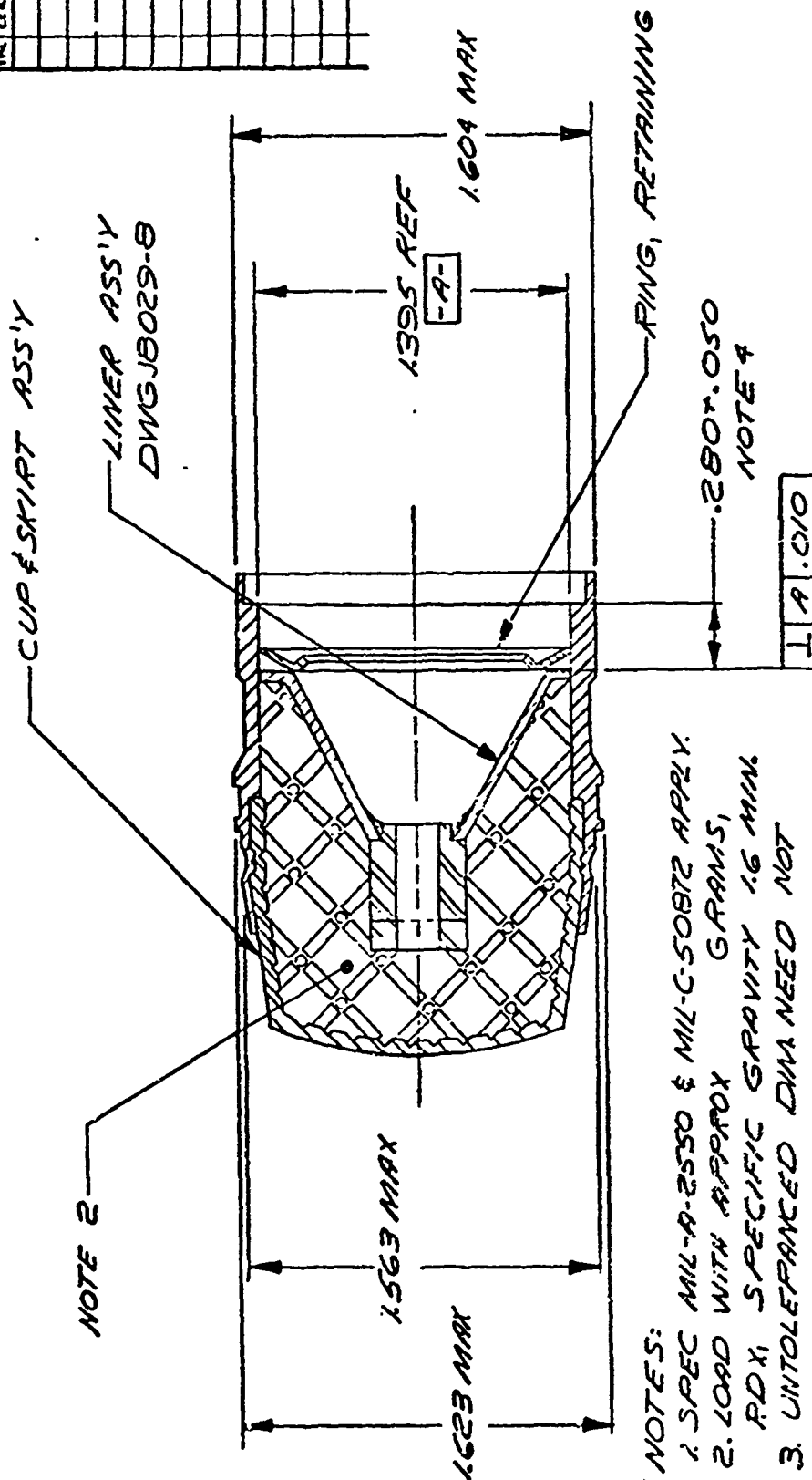
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	.00			DATE OF PRINT			
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NOTE: 1 SPEC MIL-STD-100 APPLIES.

[illegible]

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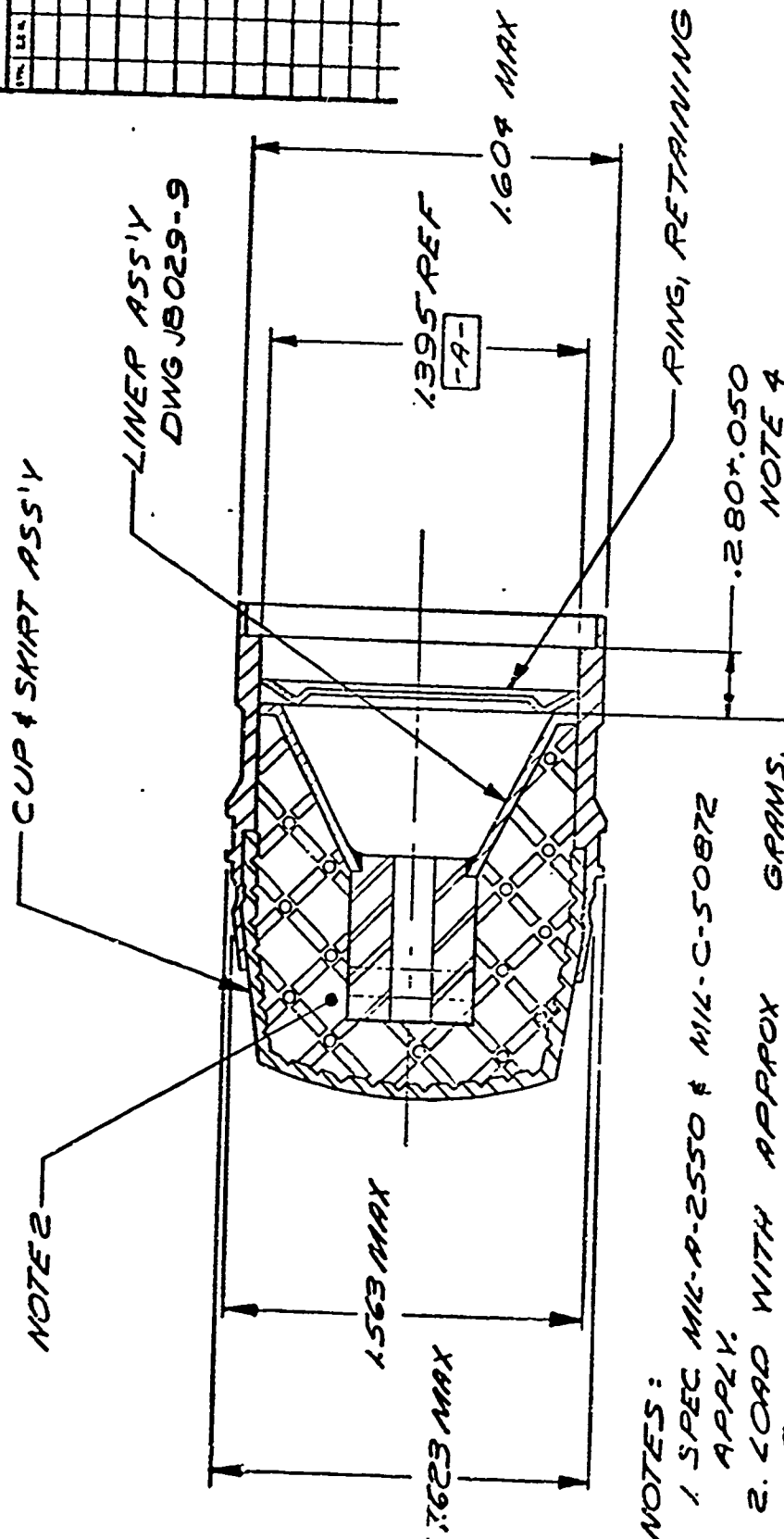
[illegible]

- NOTES:
1. SPEC MIL-A-2550 & MIL-C-50872 APPLY.
 2. LOAD WITH APPROX GRAMS, PDX, SPECIFIC GRAVITY 1.6 MIN.
 3. UNTOLERANCED DIA NEEDED NOT BE GAGED.
 4. LINER ASSY SHALL BE USED TO COMPLETE FINAL CONSOLIDATION OF THE PDX CHARGE.
 5. PHANTOM LINE INDICATES .3 CONE DIA LENGTH.

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	CUP & BCD LINER		
	LADING	ASS'Y		
	MATERIAL	SEE DETAILS		
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NAME	CUP & BCD LINER	
LADING	ASS'Y	
MATERIAL	SEE DETAILS	
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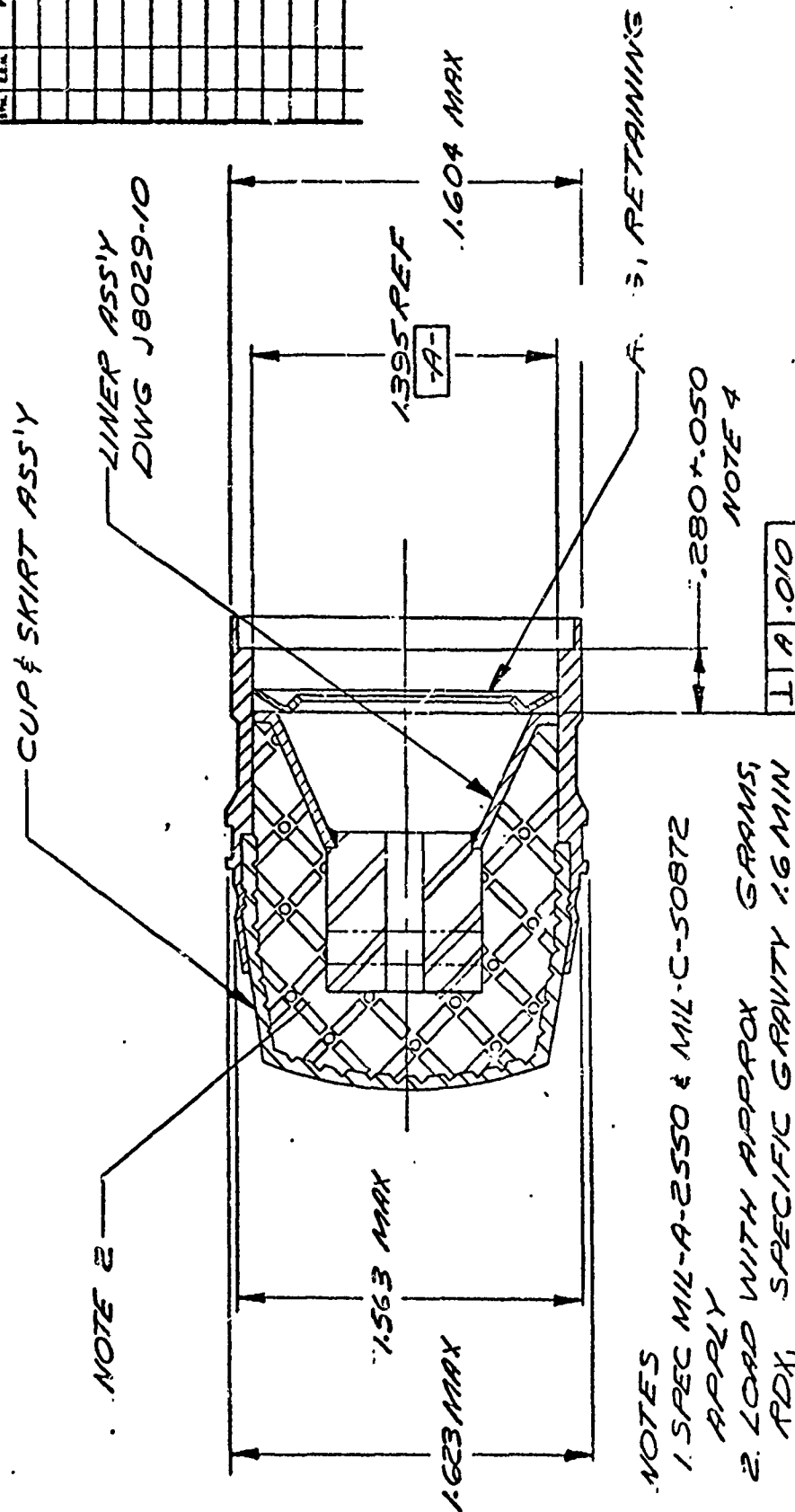
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APPROVED		7/7/73
SCALE	3/1	
DATE OF PRINT		
DESTROY PREVIOUS ISSUES		
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- NOTES:
1. SPEC MIL-A-2550 & MIL-C-50872 APPLY.
 2. LOAD WITH APPROX GRAMS, RDX, SPECIFIC GRAVITY 1.6 MIN.
 3. UNTOLESPANCED DIM. NEED NOT BE GAGED.
 4. LINER ASSY SHALL BE USED TO COMPLETE FINAL CONSOLIDATION OF THE RDX CHARGE.
 5. PHANTOM LINES INDICATE .3 & .4 CONF DIA LENGTHS.

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME CUP & ACD LINER		DRAWN DRB	DAYS 23/5/71
	LOADING ASS'Y			
PRAC.	MATERIAL SEE DETAILS		CHECKED CH	DATE 5/3/73
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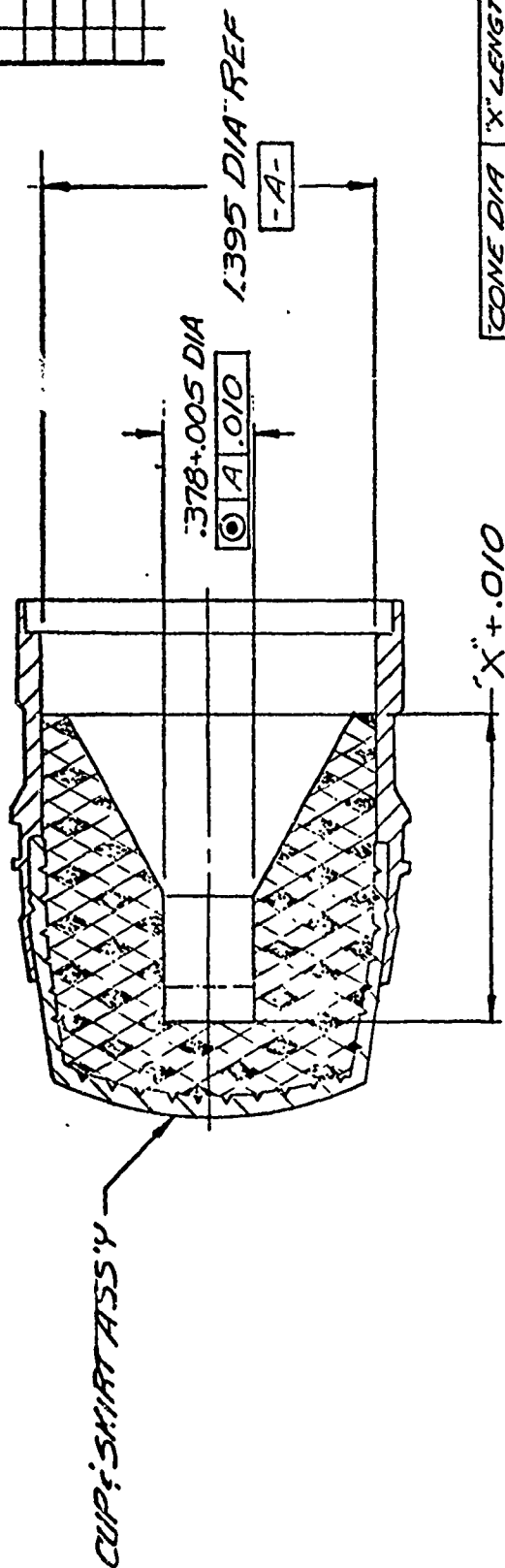
J8029-12

[illegible]

- NOTES
1. SPEC MIL-A-2550 & MIL-C-50872 APPLY
 2. LOAD WITH APPROX GRAMS, RDX, SPECIFIC GRAVITY 1.6 MIN
 3. UNTOLERANCED DIM NEED NOT BE GAGED.
 4. LINER ASSY SHALL BE USED TO COMPLETE FINAL CONSOLIDATION OF THE RDX CHARGE.
 5. PHANTOM LINES INDICATES .34 CONE DIA LENGTHS.

	UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME CUP & .5 CD LIMER LOADING ASS'Y	DRAWN DRB DATE 7/5/76
		MATERIAL SEE DETAILS	DATE OF PRINT
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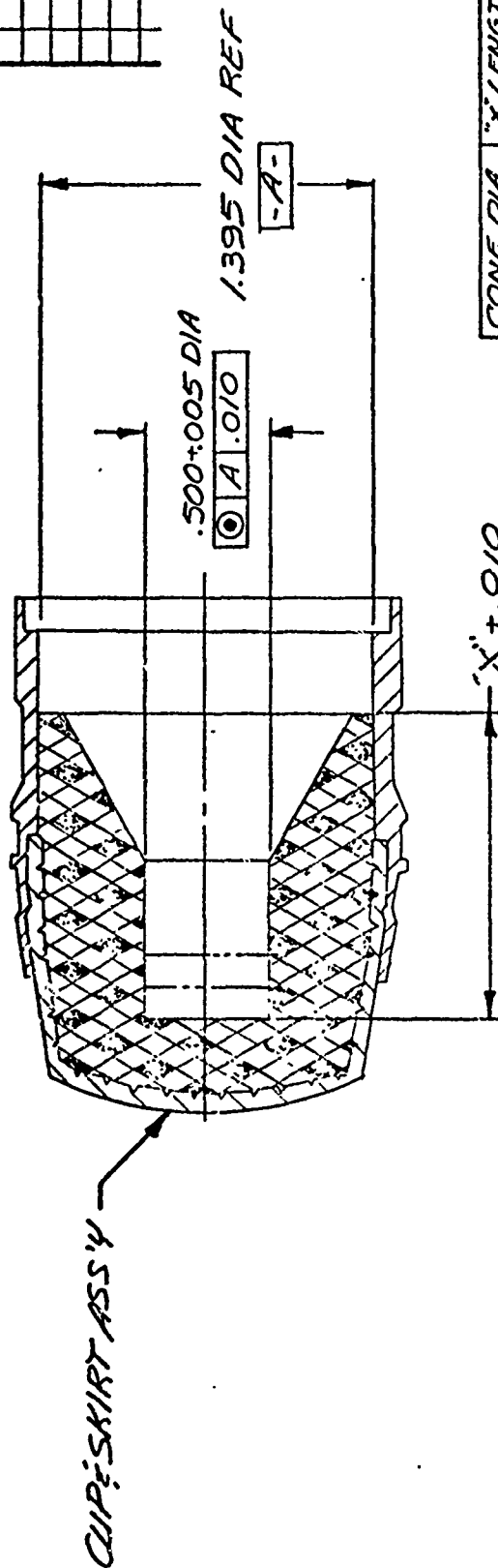
U8029-13

[illegible]

NOTES:
1. SPEC MIL-A-2550; MIL-C-50872
APPLY

CONC DIA	"X" LENGTH
.3	1.055
.4	1.180

UNLESS OTHERWISE SPECIFIED LIMITS ARE	FRAC.		NAME: 300 CLIP & LINER EXPLOSIVE DRILLED	MATERIAL	DRAWN DGC	CHECKED JAH	APPROVED	SCALE 3/1	DATE OF PRINT	2. DATE: 1-25-73	DESTROY PREVIOUS ISSUES	J8029-14
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[illegible]

CONE DIA	"X" LENGTH
.3	.942
.4	1.067
.5	1.192

NOTES:
1. SPEC MIL-A-2550 & MIL-C-50872
APPLY

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	.4CD CUP & LINER	
	MATERIAL	EXPLOSIVE DRILLED	
	FRAC.		
	.000		
ANGULAR			

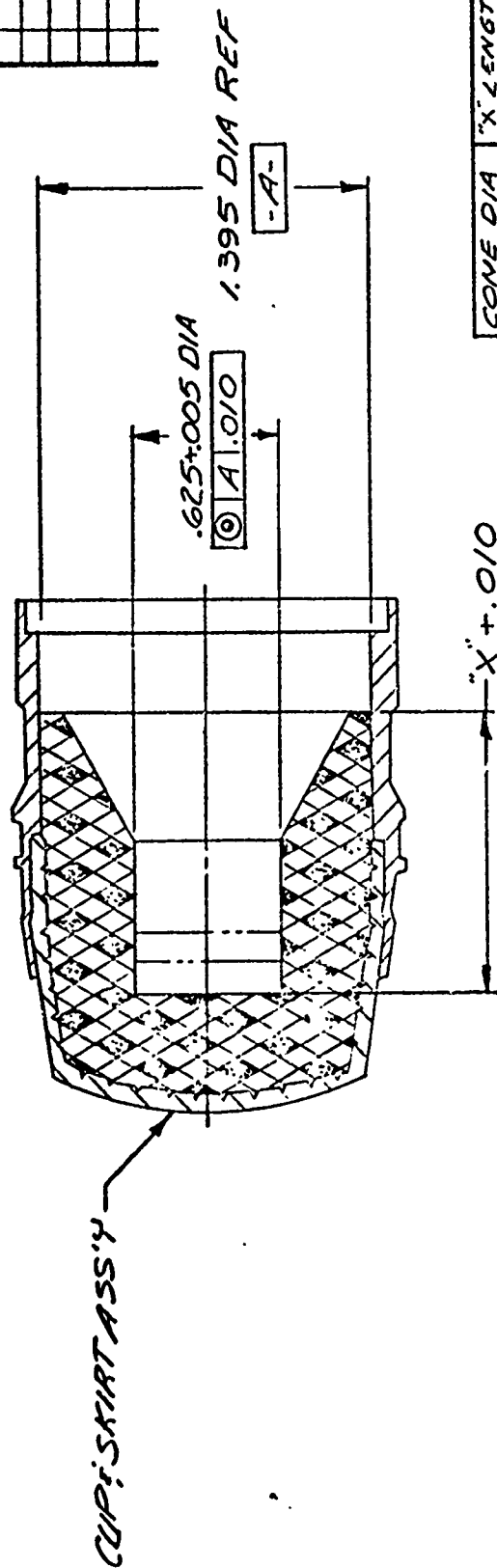
NAME	.4CD CUP & LINER	
MATERIAL	EXPLOSIVE DRILLED	
DRAWN	DATE	BY
CHECKED	DATE	BY
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DATE OF PRINT		
DESTROY PREVIOUS ISSUES		
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CHAMBERLAIN

MANUFACTURING CORPORATION

WATERLOO, IOWA

J8029-15

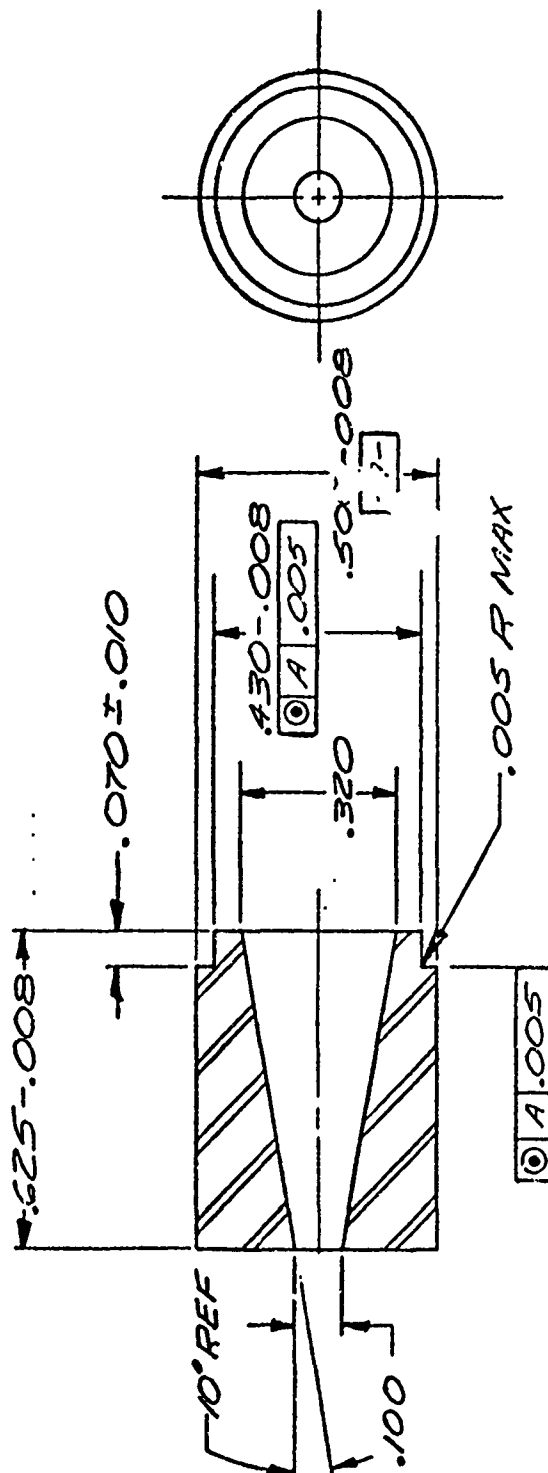
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CONC DIA	"X" LENGTH
.3	.830
.4	.955
.5	1.080

NOTES:
1. SPEC MIL-A-25504 MIL-C-50872
APPLY

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME .5CD CUP LINER	DRAWN DSC	DATE: 7-2-53
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		MATERIAL	APPROVED	
			SCALE 2/1	
		CHAMBERLAIN	DATE OF PRINT	
		MANUFACTURING CORPORATION	DESTROY PREVIOUS ISSUES	
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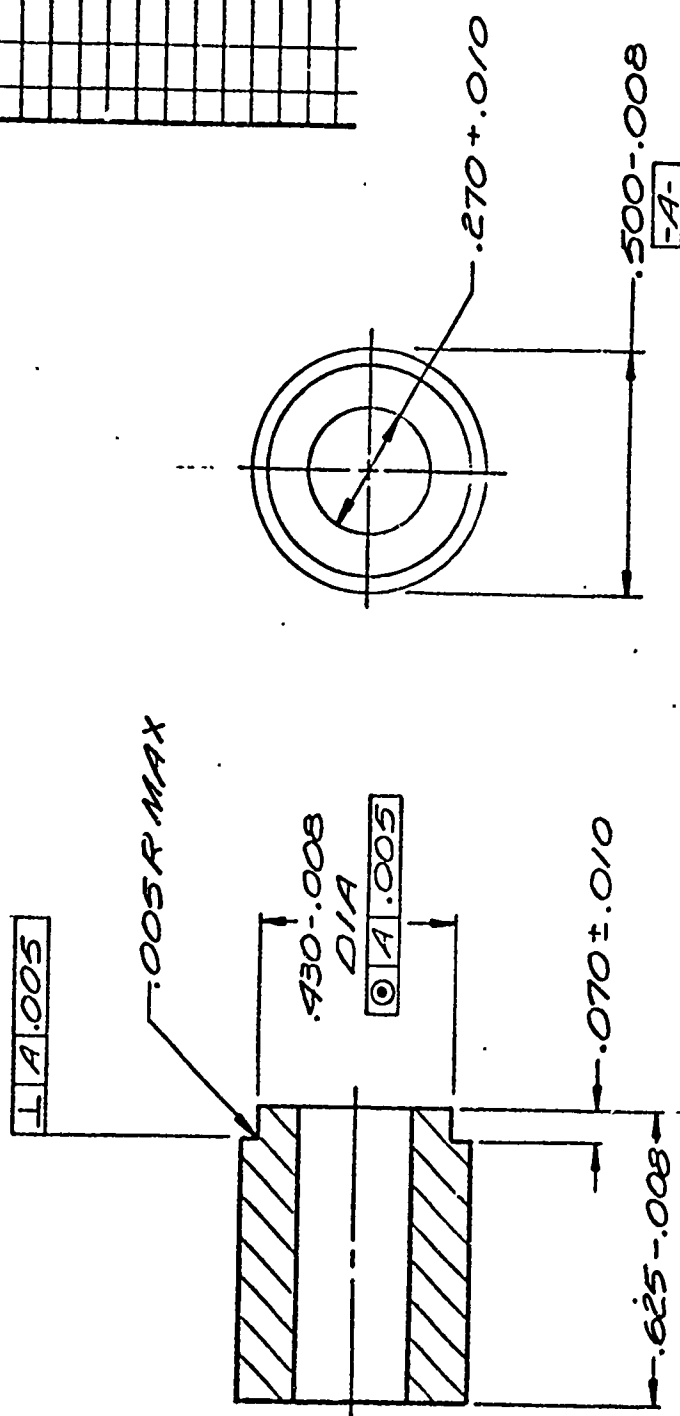
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NOTES:

1. INTERPRET DWG IN ACCORDANCE WITH MIL-STD-100
2. MATERIAL: INCENDIARY, MISC OR ZIRCONIUM.
3. REMOVE ALL BURRS AND SHARP EDGES .02 MAX

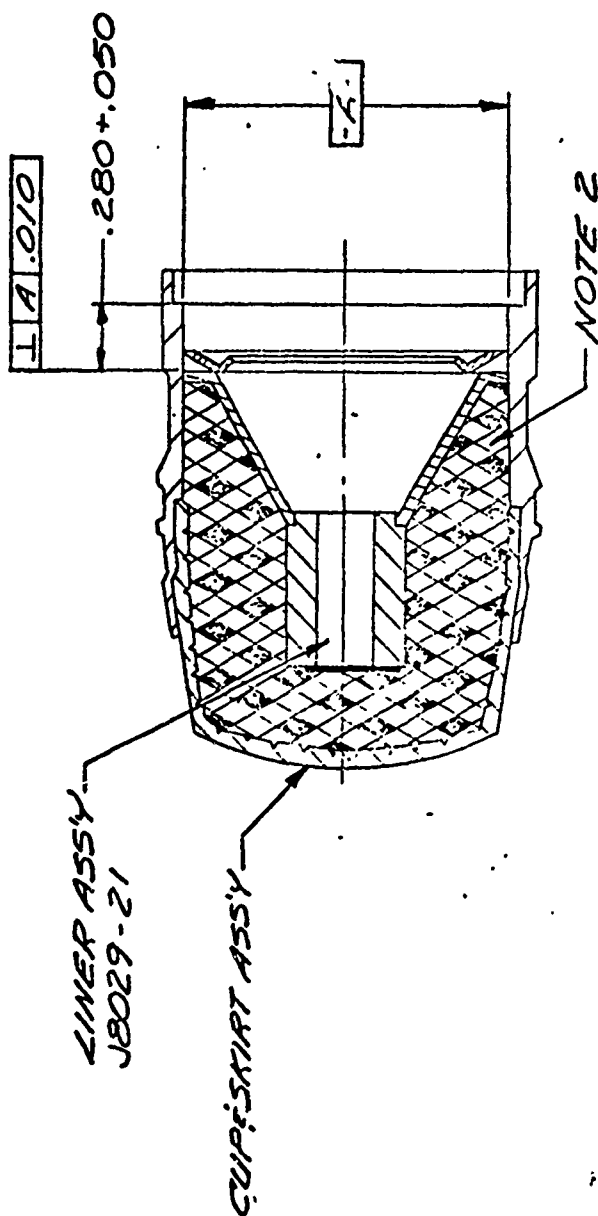
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1. SPEC MIL-A-2550 APPLIES
2. BREAK SHARP CORNERS
- .02 MAX

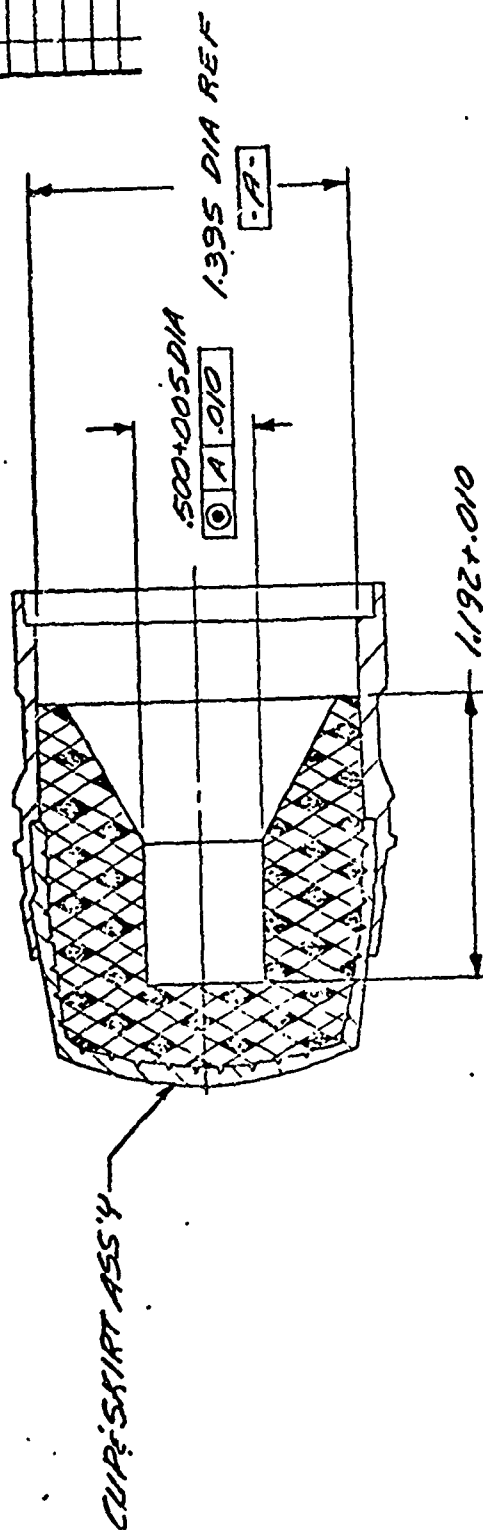
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			DATE OF PRINT	
			DESTROY PREVIOUS ISSUES	
			<i>J8029-18</i>	

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NOTES:
1. SPEC MIL-A-2550 AND
MIL-C-50872
2. LOAD WITH APPROX 43.0 GRAMS.
RDX SPECIFIC GRAVITY 1.6
MIN

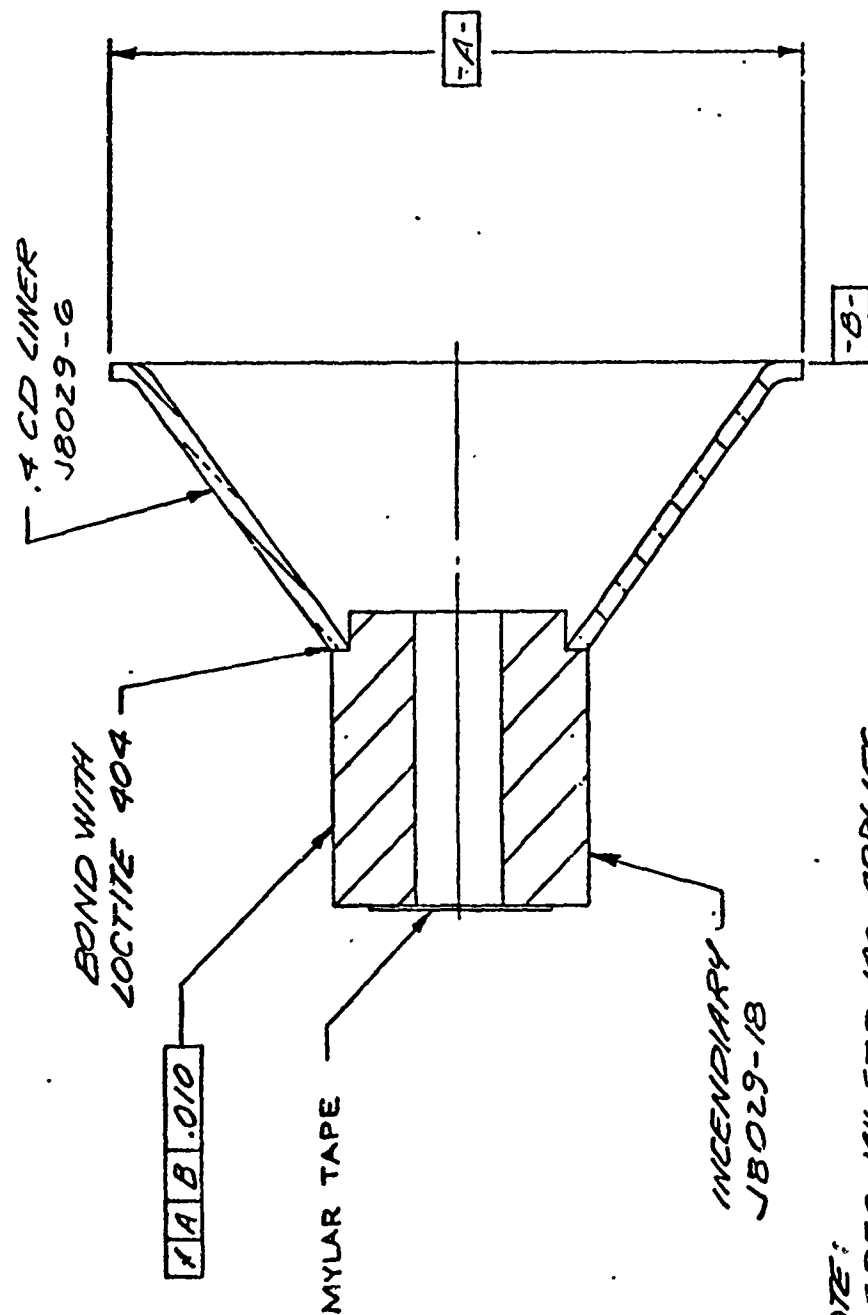
UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	LOADING ASS'Y	DRAWN	DSC	EXDATERM
	MATERIAL	SEE DETAILS		CHECKED	
FRAC.			APPROVED		
000			SCALE	2 1/2	
00			DATE OF PRINT		
0			DESTROY PREVIOUS ISSUES		
ANGULAR			JAO 29-19		

J8029-19

[illegible]

NOTES:
1. SPEC MIL-A-2550, MIL-C-50872
APPLY

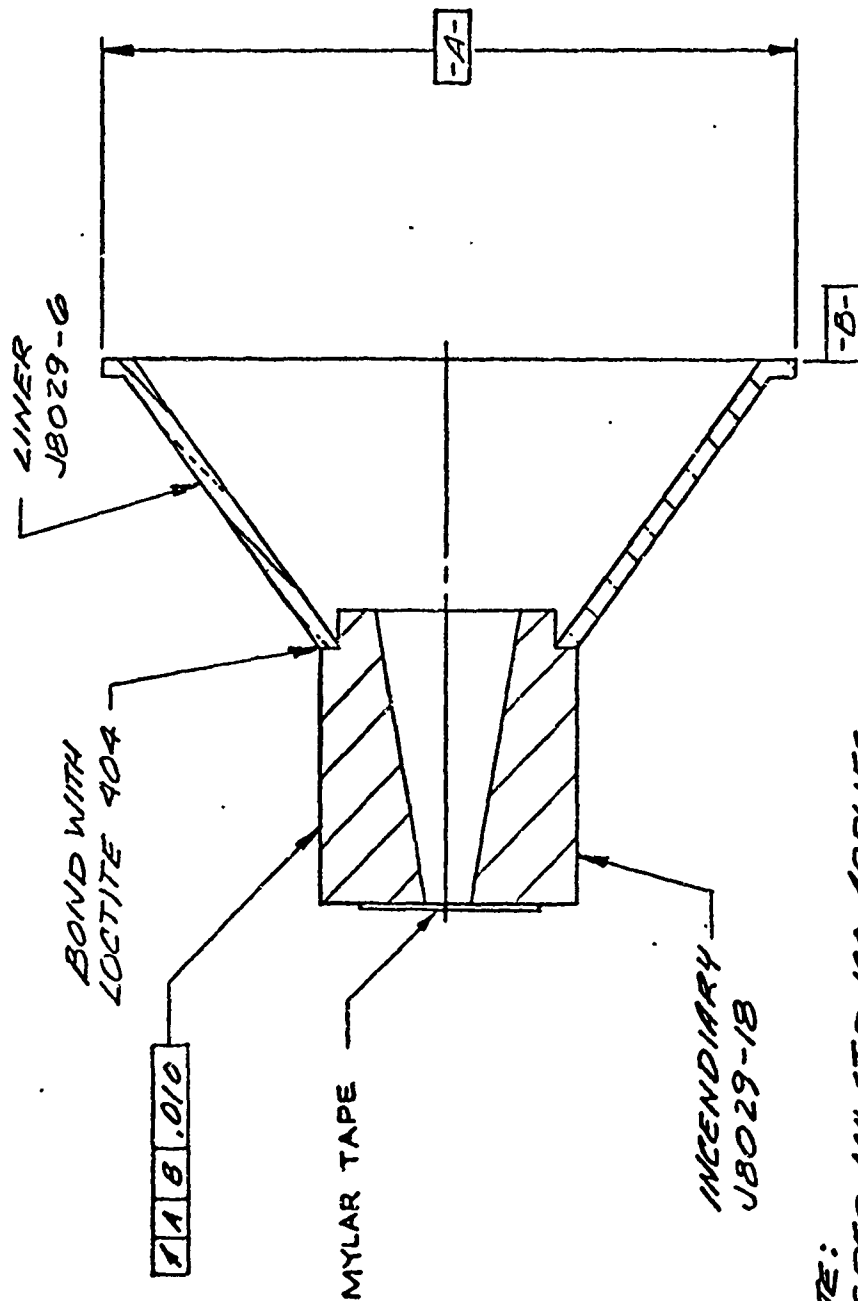
[illegible]

[illegible]

NOTE:
1. SPEC MIL-STD-100 APPLIES

NAME LINEAR ASSEMBLY	DRAWN DEC		DATE 12/1/54
	CHECKED T.C.H.		DATE 12/1/54
	APPROVED		
	SCALE 4/1		
	DATE OF PRINT		
UNLESS OTHERWISE SPECIFIED LIMITS ARE		DESTROY PREVIOUS ISSUES	
FRAC.	.000	18029-21	
	.00		
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MATERIAL SEE DETAILS			
CHAMBERLAIN			
MANUFACTURING CORPORATION			
WATERLOO, IOWA			

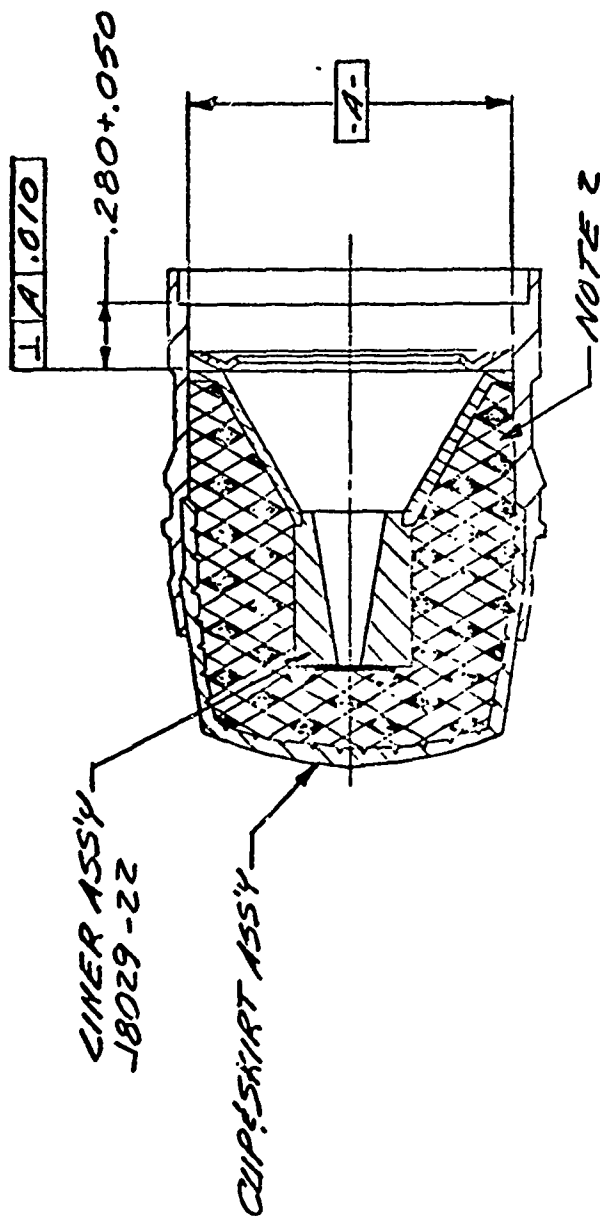
J8029-2/

[illegible]

NOTE:
1. SPEC MR-STD-100 APPLIES

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	LINER ASSEMBLY		DRAWN	DBC	REVISED	APR 74
	MATERIAL	SEE DETAILS		CHECKED	JCA	DATE	15 May 74
	FRAC.			APPROVED			
	ODD			SCALE	1/1		
	OO			DATE OF PRINT			
•			DESTROY PREVIOUS ISSUES				
ANGULAR			180229-22				

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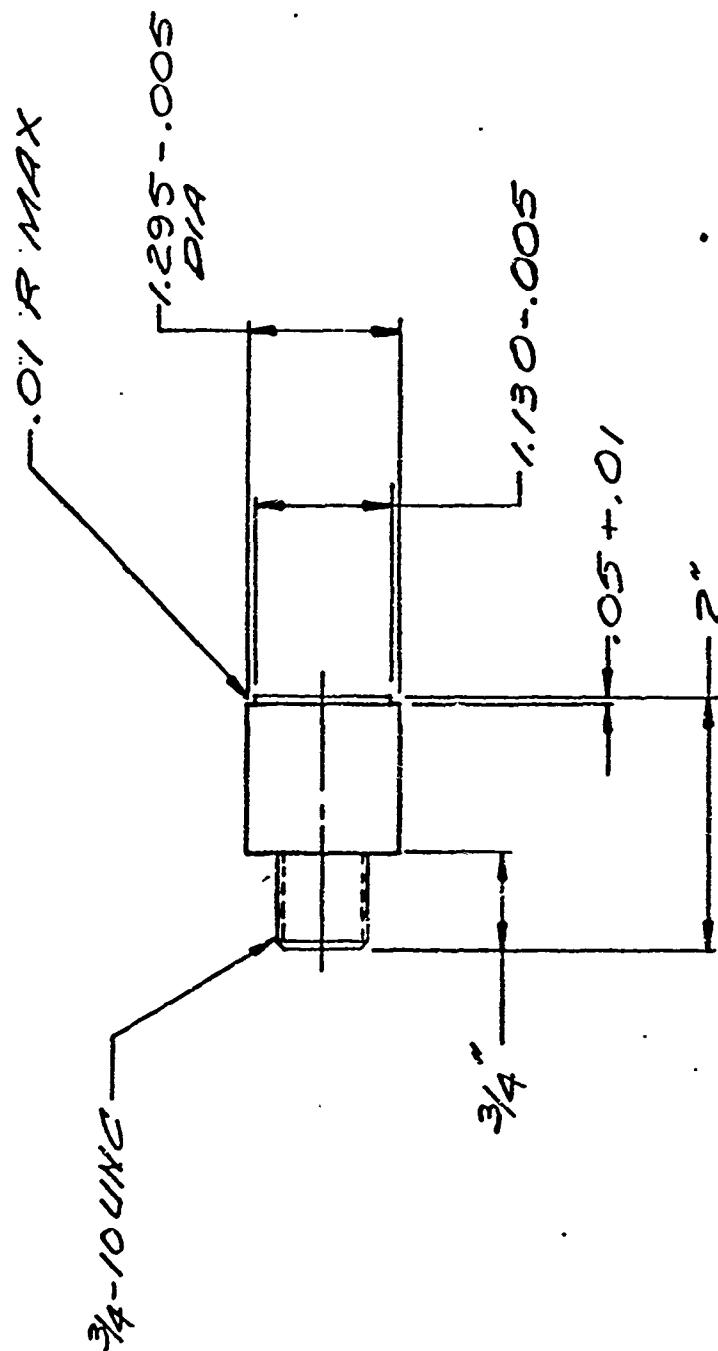
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NOTES:
1. SPEC MIL-A-2550 AND
MIL-C-5087Z
2. LOAD WITH APPROX 430 GRAMS
RDX SPECIFIC GRAVITY
1.6 MIN

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	LOADING ASS'Y	DRAWN	EXC. P. CO.'S.
	MATERIAL	SEE DETAILS	CHECKED	J.C.H. 16 MAR '74
	FRAC.		APPROVED	
	000		SCALE	2/1
			DATE OF PRINT	
.00				DESTROY PREVIOUS ISSUES
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CHAMBERLAIN
MANUFACTURING CORPORATION
WATERLOO, IOWA

78029-23

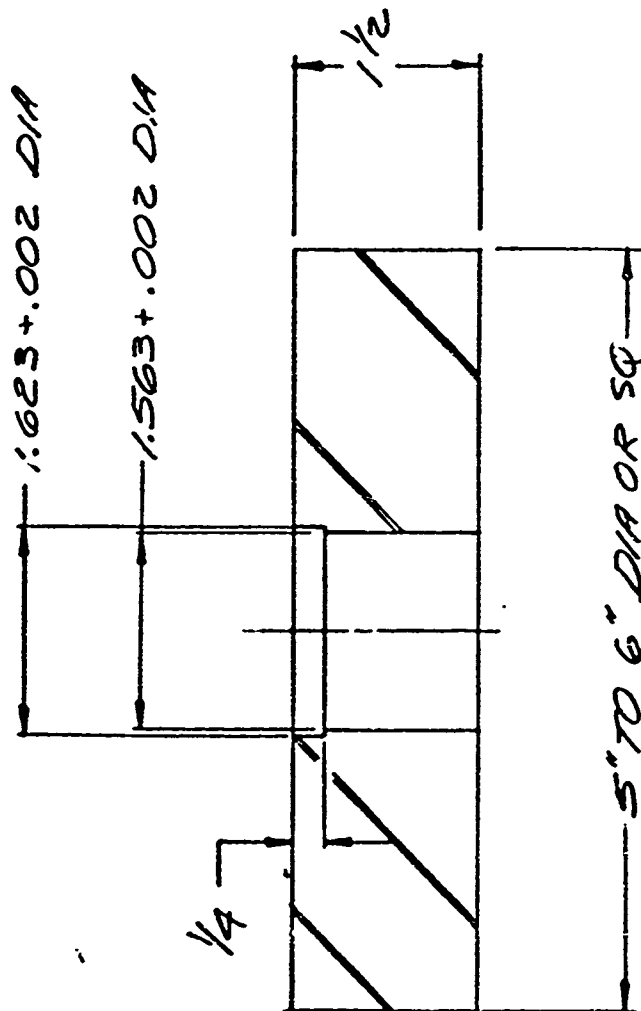
[illegible]

UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME <i>PUNCH</i>	DRAWN <i>DSL</i>	DATE: <i>8-2-54</i>
		CHECKED	
		APPROVED	
	MATERIAL <i>STEEL A36</i>	SCALE <i>1"</i>	
	DATE OF PRINT		
	DESTROY PREVIOUS ISSUES		
	<i>J5029-2A</i>		

CHAMBERLAIN

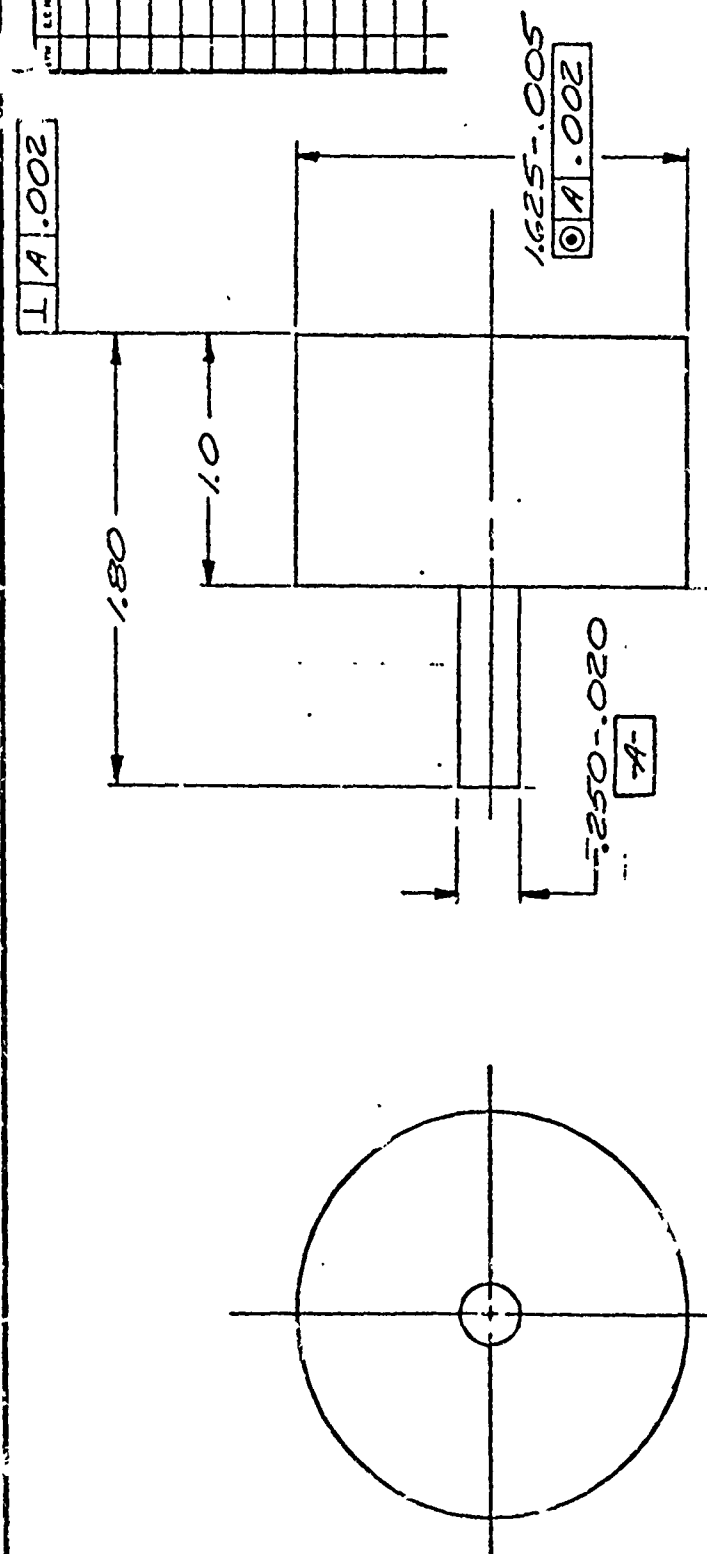
MANUFACTURING CORPORATION

WATERLOO, IOWA

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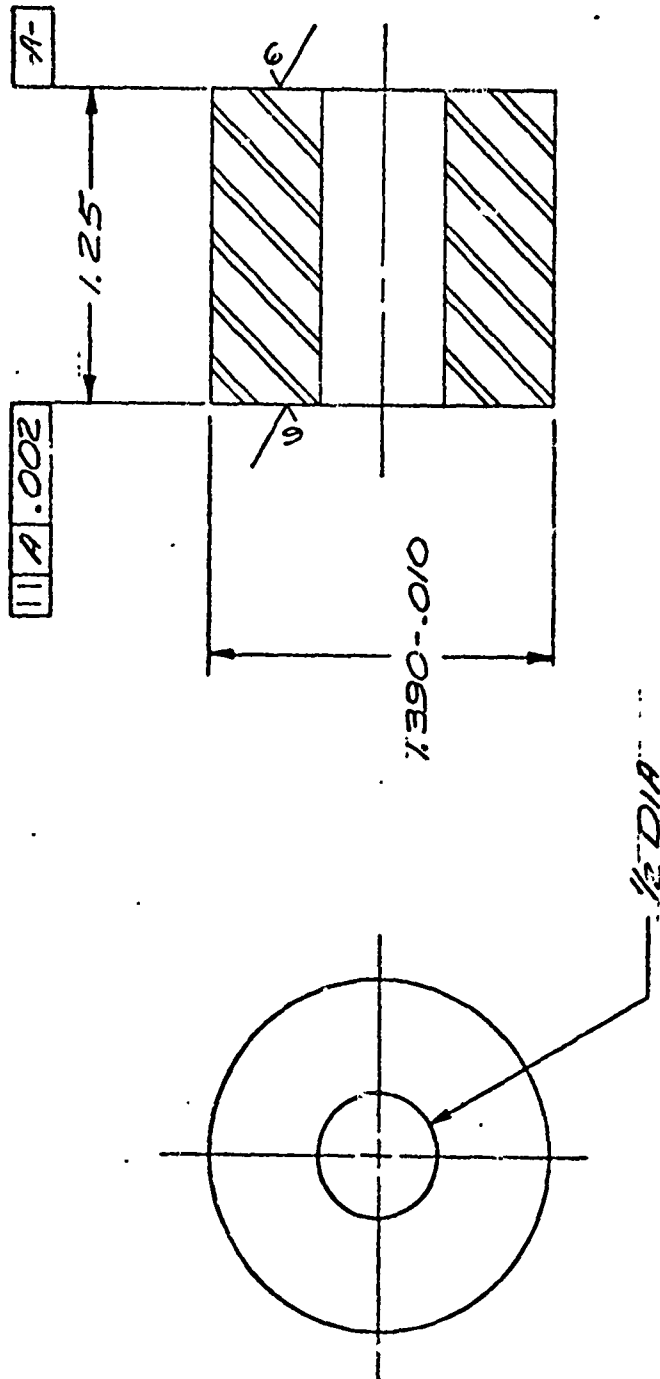
UNLESS OTHERWISE SPECIFIED LIMITS ARE	NAME	DIE BLOCK	
	MATERIAL	STEEL ANY	
	<div>CHAMBERLAIN</div> <div>MANUFACTURING CORPORATION</div> <div>WATERLOO, IOWA</div>		
	<div>DRAWN DSC</div> <div>CHECKED JED</div> <div>APPROVED</div> <div>SCALE 1/1</div> <div>DATE OF PRINT</div> <div>DESTROY PREVIOUS ISSUES</div> <div>U8029-3A</div>		
PRAC			
100			
00			
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ANGULAR			

✓B029-3A

[illegible]

UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME EXPLOSIVE DRILLING LOCATING FIXTURE MATERIAL	CHAMBERLAIN MANUFACTURING CORPORATION WATERLOO, IOWA	DRAWN <i>DRB</i> DATES <i>11/15/55</i> CHECKED <i>JUL</i> " " APPROVED SCALE <i>3/1</i> DATE O. PRINT	DESTROY PREVIOUS ISSUES <i>JB029-4A</i>
FRAC.	000				
	00				
	.0				
ANGULAR					

J8029-4A

[illegible]

UNLESS OTHERWISE SPECIFIED LIMITS ARE	FRAC		NAME SAGE, EXPLOSIVE DISTILLING	DRAWN <i>CRS</i> CHECKED <i>IND</i> APPROVED	DATES 5/11/55 " "
	COO				
	.00	$\pm .00$			
	.0				
ANGULAR					

CHAMBERLAIN
MANUFACTURING CORPORATION
WATERLOO, IOWA

MATERIAL *STEEL*

SCALE *2/1*

DATE OF PRINT

DESTROY -- PREVIOUS ISSUES
18029-1C

18029-15

2. Material Specification for Zirconium Particles

PRELIMINARY
MATERIAL SPECIFICATION
FOR ZIRCONIUM PARTICLES

OS-ZP-02

OCTOBER 11, 1972

Prepared By: R. E. Curtis
R. E. Curtis

Approved By: S. A. Worcester
S. A. Worcester

PRELIMINARY
MATERIAL SPECIFICATION
FOR ZIRCONIUM PARTICLES

OS-ZP-02
OCTOBER 11, 1972

1. SCOPE

- 1.1 This specification covers one type of zirconium particles for ordnance use.

2. APPLICABLE DOCUMENTS

- 2.1 Government Documents: The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

RR-S-366 Sieve, Test

Military

MIL-I-45208 Inspection System Requirements

STANDARDS

Military

MIL-STD-129 Marking for Shipment and Storage

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

- 2.2 Non-Government Documents: The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society of Testing Materials:

STANDARDS

ASTM Method E10 Test for Brinell Hardness of Metallic Materials

ASTM D1193 Reagent Water

(Application for copies should be addressed to the American Society for Testing Materials, 1916 Race Street, Philadelphia, PA 19103.)

3. REQUIREMENTS

3.1 General Material Requirements: Zirconium particles furnished under this specification shall be particulate and of irregular shape.

3.1.1 Particle Size: When screened through a test sieve conforming to Federal Specification RR-S-366, the particles shall be retained on the screens as shown in Table I.

TABLE I
PARTICLE SIZE DISTRIBUTION BY SCREENING

<u>Screen Retained on</u>	<u>Opening Inches</u>	<u>Percent</u>
6 mesh	.131	10.0 maximum
80 mesh	.0069	80.0 minimum
pan		10.0 maximum

3.1.2 Composition: Material composition shall conform to the requirements set forth in Table II.

TABLE II
CHEMICAL REQUIREMENTS

<u>Element</u>	<u>Percentage</u>
Zirconium + Hafnium	98.0 minimum
Chloride	0.3 maximum
Impurities	2.0 maximum

- 3.1.3 Hardness: When arc melted into a metal button, the hardness of the material shall conform to the requirement shown in Table III. Hardness tests shall be conducted in accordance with ASTM Method E10, using a 10mm ball and 3000 kg load.

TABLE III

BRINELL HARDNESS REQUIREMENT

BHN	140 minimum*
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*Average of three (3) readings

- 3.2 Workmanship: Materials supplied under this specification shall be free of dirt, oil, grease, or other foreign material within the limits specified in Section 3.1.2.
- 3.3 Certification: Zirconium particles furnished under this specification shall be certified prior to production delivery.

4. QUALITY ASSURANCE PROVISIONS

- 4.1 Responsibility for Inspection: Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the buyer. The buyer reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.
- 4.1.1 Inspection System: The suppliers inspection system shall conform to Specification MIL-I-45208.
- 4.2 Certification Provisions: Material to be certified under this specification shall be subjected to tests listed in Table IV. The certification sample will be rejected if the sample fails to comply with any of the applicable requirements.

TABLE IV
CERTIFICATION TESTS

<u>Test</u>	<u>Requirement</u>	<u>Test Method</u>
Particle Size	3.1.1	4.4.1
Composition	3.1.2	4.4.3
Hardness	3.1.3	4.4.2

4.3 Quality Conformance Inspection: Material supplied under this specification shall be inspected for acceptance.

4.3.1 Visual Inspection: Each container of packaged material shall be visually inspected for complete, correct, legible marking and workmanship.

4.3.2 Material Acceptance Tests: Samples shall be tested as specified in Table V for acceptance. Material will be rejected if the samples fail to comply with any of the applicable requirements.

TABLE V
MATERIAL ACCEPTANCE TESTS

<u>Test</u>	<u>Requirement</u>	<u>Test Method</u>
Particle Size	3.1.1	4.4.1
Composition	3.1.2	4.4.3
Hardness	3.1.3	4.4.2

4.4 Test Methods

4.4.1 Particle Size: Using the required screen (6 mesh and 80 mesh) per Specification RR-S-366, nest the sieves on a bottom pan. Place an approximately 100 gram sample on the upper sieve. Cover the sieve and shake for five (5) minutes in a mechanical shaker.

Weigh the amount retained on each screen and on the pan to the nearest 0.01 gram. Calculate the required percentages.

- 4.4.2 Hardness: Compact a 150 gram sample of zirconium particles into a briquette. Arc melt the briquette in a protective atmosphere into a metal button and machine both surfaces flat. Conduct Brinell hardness tests on one side of the machined button according to ASTM Method E10 using a 10mm ball and a 3000 kg load.
- 4.4.3 Composition Tests: Percentage of all elements except chloride shall be determined by current TWCA spectrographic methods. Zirconium + hafnium shall be determined by difference and shall be calculated to the nearest 0.1%. The test report shall indicate measured percentage of each element which constitutes 0.5% or more by weight of the material. Chloride will be determined by a current TWCA wet chemical technique. Reagent grade chemicals and distilled water in accordance with ASTM D1193 shall be used in all chemical tests.

5. PREPARATION FOR DELIVERY

- 5.1 Packaging, Level C: Net weight of the unit package and contents shall not exceed 500 pounds. The unit container must support superimposed loads during transportation and storage. Containers shall be clean and free of any foreign material which may contaminate the contents.
- 5.2 Labeling and Marking: Marking shall be in accordance with MIL-STD-129 when required.

6. ORDERING DATA

Procurement documents should specify the title, number and date of this specification.